

Fixture Congestion and the Physical Response to Soccer: Implications for Knee Flexor Injury Risk

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ABSTRACT

Congested activity schedules are common in soccer, with implications for impaired performance and increased injury risk. It has recently been suggested that valid soccer-specific exercise protocols (SSEP's) may offer a unique opportunity to assess the physical demands associated with periods of fixture congestion. Fixture congestion in the current thesis is defined as a high frequency of soccer-specific activity performed with less than or equal to seventy-two hours of recovery interspersing successive bouts. Study one describes the development of a novel treadmill-based SSEP characterised by clusters of high intensity (HI) efforts. The SSEP was validated against the velocity profile and total distance (TD) covered, and elicited a physical response comparable to match-play. Study two utilised the same SSEP to consider the physical response associated with successive bouts of soccer-specific activity interspersed with either 48 or 72h recovery. There was no difference in the fatigue response associated with two soccer simulations, with 48 h sufficient for full recovery of the physiological and PlayerLoad™ data. The 48 h recovery was therefore applied in Study three, where three games in a week is typically the worst case scenario for fixture congestion. Study three quantified the cumulative and residual physiological and biomechanical response associated with the completion of three successive bouts of the SSEP, completed with 48 hrs recovery between each trial. Study three also assessed the physical response associated with successive bouts of different exercise modalities (continuous, repeat-sprint, and intermittent), specific to the demands of the SSEP. The physical response was specific to each activity modality, but the volume of work and number of HI efforts performed across the three SSEP's elicited a mechanical and muscular emphasis with residual fatigue. Study four attempted to assess the effectiveness of an interchange rule on reducing the cumulative and residual physical fatigue response associated with the completion of the SSEP. The interchange rule appeared to elicit a positive effect on the physiological and perceptual response to, and rate of mechanical recovery following the completion of the SSEP. Study five focussed on developing and assessing the effectiveness of a novel post-match active recovery protocol on aiding the rate of post-trial mechanical and perceptual recovery. The active recovery protocol had a positive effect on the eccentric knee flexor angle of peak torque data recorded at 300 deg·s⁻¹. The current series of studies offers a mechanistic understanding of the physical response associated with periods of short-term fixture congestion in soccer. The current studies have implications for the design and micro management of training and competition schedules, and the contemporary use of biomechanical analyses to quantify markers of performance and injury.

Key words: Biomechanics, Fatigue, Fixture Congestion, Injury, Physiology, Recovery, Soccer

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LIST OF ABBREVIATIONS AND ACRONYMS

Ag/AgCl	Silver-silver chloride
APT	Angle of peak torque
ATP	Adenosine triphosphate
ADP	Adenosine diphosphate
ARF	Australian rules footballers
BEAST ₉₀	Ball sport endurance and sprint test
BF	Bicep femoris
BLa	Blood Lactate
CD	Compact disc
CI	Confidence intervals
CK	Creatine kinase
CMJ	Counter movement jump
COD	Changes of direction
CONT	Continuous protocol
CST	Copenhagen soccer test
EIMD	Exercise induced muscle damage
EMG	Electromyography
EMG/M	Electromyography amplitudes
EMG _{Avpeak}	Average peak electromyography
EMG _{mean}	Mean electromyography
EMG _{pk}	Peak electromyography
EPL	English Premier League
FFA	Free fatty acids
FIFA	Fédération Internationale de Football Association
FR	Functional range
FR ₈₀	Functional range 80% of peak torque
FT:CT	Flight time: contraction time
GC	Gastrocnemius
GLM	Repeated measures general linear model

GPS	Global positioning system
H	High
HI	High intensity
HR	Heart rate
HR _{peak}	Peak heart rate
HT	Half-time
ICC	Intraclass correlation coefficients
iEMG	Integrated electromyography
IKD	Isokinetic dynamometer
INT	Intermittent protocol
KE	Knee extensors
KF	Knee flexors
L	Low
LH	Leg heaviness
LI	Low intensity
LIST	Loughborough intermittent shuttle test
M	Moderate
MH	Medial hamstring
MS	Perceived muscle soreness
MVC	Maximal voluntary contraction
<i>N</i>	Number of participants
PCr	Phosphocreatine
pH	Potential hydrogen
PL _{AP}	Anterior-posterior PlayerLoad™
PL _{AP%}	Relative contribution of anterior-posterior PlayerLoad™
PL _{ML}	Medial-lateral PlayerLoad™
PL _{ML%}	Relative contribution of medial-lateral PlayerLoad™
PL _{total}	Tri-axial PlayerLoad™
PL _V	Vertical PlayerLoad™
PL _{V%}	Relative contribution of Vertical PlayerLoad™
PM	Purposeful movement

PT	Peak torque
PT _{MVC}	Maximal isometric torque
RF	Rectus femoris
RMS	Root mean squared
RPE	Rating of perceived exertion
RS	Repeat-sprint protocol
SAFT ⁹⁰	Soccer-specific aerobic field test
SD	Standard deviation
SMS	Soccer match simulation
SSEP	Soccer-specific exercise protocol
TA	Tibialis anterior
TD	Total distance
TQR	Perceived total quality of recovery
UEFA	Union of European Football Associations
VAS	Visual analogue scale
$\dot{V}CO_2$	Carbon dioxide production
VE	Minute ventilation
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2max}$	Maximal oxygen consumption
vs.	Versus
$v-T_{lac}$	Lactate threshold running velocity
η^2	Partial eta squared

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Soccer is a team based sport which is characterised by a self-paced, irregular, multi-directional and intermittent activity profile, with HI bouts of activity interspersed by periods of low intensity (LI) active and passive recovery (Bangsbo, 1994; Varley and Aughey, 2013). Time motion analysis literature often reports a total distance (TD) covered of ~10-12 km (Saltin, 1973; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988; Bangsbo, et al., 1991; Mohr et al., 2003; Di Salvo, et al., 2007; Barros et al., 2007; Rampinini et al., 2007; Bradley et al., 2009; Barnes et al., 2014), with a change in activity every 5-6s (Strudwick et al., 2002; Mohr et al., 2003; Reilly 2003). The majority of soccer match is performed at submaximal locomotion speeds (Mohr et al., 2003), thus suggesting a predominantly aerobic contribution. However, the bouts of HI activity and often the most decisive actions during soccer match-play also rely on high anaerobic-energy turnover (Stølen et al., 2005). Successful performance in team sports is therefore related to the capacity to cope with repeated bouts of HI exercise and in turn prolong the onset of fatigue (Mohr et al., 2003; Rampinini et al., 2007; Bangsbo et al., 2007; Impellizzeri et al., 2008; Rampinini et al., 2009).

In the most recent Union of European Football Associations (UEFA) injury audit (Ekstrand et al., 2011), it was identified that injury incidence associated with both training and match-play remained consistent between 2001 and 2008. These data suggests that even with advancements in sport science and medicine, injury incidence remains high. As such, injury incidence continues to pose a contemporary issue associated with modern soccer. Moreover, both the UEFA injury audit (Ekstrand et al., 2011) and a Football Association audit published 10 years previously (Hawkins et al., 2001), identified an increased injury incidence towards the end of each half of match-play. This data mirrors the observed reductions in physical performance identified towards the latter stages of match-play (Mohr et al., 2003; Bradley et al. 2009), and identifies fatigue as a potential risk factor for injury in intermittent team sports (Hawkins et al., 2001; Gabbett 2003; Ekstrand et al., 2011). Fatigue in soccer can occur temporarily following a period of HI activity (Mohr et al., 2003), cumulatively towards the end of a match (Krustrup et al., 2006b), and residually between successive bouts of match-play (Carling et al., 2015).

Previous time-motion analysis literature has identified an increased physical demand of modern soccer match-play. Data collected from the English Premier League (EPL) identified that HI running distance, number of actions number of sprints, and sprint distance were higher in the 2012-2013 season when compared to the 2006-2007 season

(Barnes et al., 2014). Modern soccer players are also required to compete in a high frequency of matches (50-60), with only 2-4 days recovery between successive matches (Dupont et al., 2010; Strudwick, 2012; Rollo et al., 2014; Carling et al., 2015; Dellal et al., 2015). An increase in the frequency of matches, a reduction in the interspersing recovery periods, and the increased demands of the modern game may result in a high residual fatigue response between successive matches with implications for performance (Odetoynbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) and injury risk (Dupont et al., 2010; Bengsston et al., 2013; Carling et al., 2012; Dellal et al., 2015).

Changes in physical performance and injury risk during congested fixture periods have typically been assessed using data collected from actual match-play (Odetoynbo et al., 2007; Carling et al., 2010; Dupont et al., 2010; Rey et al., 2010; Lago Peñas et al., 2011; Carling et al., 2012, Bengsston et al., 2013; Djaoui et al., 2014; Dellal et al., 2015; Folgado et al., 2015), with these studies often reporting inconsistent findings. It has therefore recently been suggested that valid SSEP's may offer a unique opportunity to mechanistically assess the physical demands associated with periods of fixture congestion (Carling et al., 2015).

There currently exists a plethora of both treadmill (Abt et al., 1998; Drust et al., 2000ab; Greig et al., 2006; Clarke et al. 2012; Aldous et al., 2014) and free running based (Bishop, et al., 1999; Nicholas et al., 2000; Small et al., 2009; Williams et al., 2010; Russell et al., 2011; Bendiksen et al., 2012) SSEP's designed to assess the effects of fatigue following the completion of a 90 min soccer match. The aforementioned protocols typically do not accurately replicate soccer match play as they fail to replicate the activity profile and/or the physical demand associated with match-play. Based on both the limitations of previous protocols and the evolutions in the demands of contemporary soccer, it can be postulated that there is a need for the development of a SSEP that more accurately replicates modern soccer match-play. As previously discussed, a new SSEP should therefore be characterised by a highly intermittent activity profile (Greig et al., 2006), clusters of HI activity (Mohr et al., 2003; Spencer et al., 2004), and a TD covered of 10-12 km (Mohr et al., 2003; Di Salvo, et al., 2007; Barros et al., 2007; Rampinini et al., 2007; Bradley et al., 2009; Barnes et al., 2014). The development of such a protocol will allow for the mechanistic assessment of the physical response associated with the completion of single and successive bouts of soccer-specific activity.

Furthermore, the velocity profile associated with modern soccer match-play could be considered as a hybrid of the continuous 10-12 km TD covered, and the repeated sprint

nature of the HI bouts. By considering these discrete characteristics of soccer match-play in isolation, the physical response associated with single and repeated bouts of different modes (continuous, repeat-sprint, and intermittent) of exercise can be compared. The assessment of these different modes of exercise will help to identify if the cumulative and residual fatigue response associated with soccer match-play is a result of the volume of activity performed, a result of the repeated HI efforts, or a complex interplay of these two factors. The development of an increased mechanistic understanding of the physical fatigue response associated with single and successive bouts of match-play will inform the development of contemporary interventions to potentially reduce the cumulative and residual fatigue response associated with soccer-specific activity.

In summary, the demands of soccer match-play have been previously well described (Saltin, 1973; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988; Bangsbo, et al., 1991; Mohr et al., 2003; Di Salvo, et al., 2007; Barros et al., 2007; Rampinini et al., 2007; Bradley et al., 2009; Barnes et al., 2014), with more recent literature suggesting an evolution in the activity profile associated with modern match-play (Barnes et al., 2014). It has also previously been identified that the onset of cumulative fatigue during the latter stages of match-play is a primary risk factor in lower limb injuries (Hawkins et al., 2001; Ekstrand et al., 2011). Residual fatigue elicited from periods of short-term fixture congestion may also increase a player's susceptibility to injury (Dupont et al., 2010; Carling et al., 2012; Bengsston et al., 2013; Dellal et al., 2015); however, the mechanisms associated with injury risk during periods of fixture congestion have received little attention. It has recently been suggested that SSEP's could be used to mechanistically assess the physical response associated with periods of fixture congestion (Carling et al., 2015). There is therefore a rationale for the development of a SSEP that replicates both the velocity profile and the physical response associated with contemporary soccer match-play, and to then utilise this SSEP to assess the physical response associated with periods of soccer-specific fixture congestion.

1.2 THESIS AIMS AND STRUCTURE OF THESIS

The aim of the thesis is twofold, firstly to assess the influence of periods of short-term fixture congestion on markers of knee flexor strain injuries, and secondly to design contemporary interventions to reduce potential injury risk during these periods. The specific objectives of this thesis are therefore: 1) To design a treadmill based SSEP, and validate both the velocity profile and the physical response associated with this protocol; 2) To examine the temporary, cumulative, and residual physical fatigue response associated

with two successive bouts of a SSEP interspersed by either 48 or 72 h recovery; 3a) To examine the temporary, cumulative, and residual physical fatigue response associated with the completion of three successive bouts of a SSEP completed with 48 h recovery interspersing each bout; 3b) To examine the temporary, cumulative, and residual physical fatigue response associated with the completion of three successive bouts of three different exercise modalities (Specific to the demands of the SSEP) completed with 48 h recovery interspersing each bout; 4) To assess the effectiveness of a contemporary rule change intervention on reducing the temporary, cumulative, and residual physical response associated with the completion of a SSEP; 5) To develop and assess the effectiveness of a novel active recovery protocol on aiding the residual physical response following the completion of a SSEP. The thesis structure comprises a review of literature pertinent to the study aims, and five experimental chapters specifically directed to each of the Aims. A general synopsis is provided, including considerations for future research, limitations, and application of the SSEP.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 INTRODUCTION

Knowledge of the physical demands and physical response to soccer match-play is essential for this thesis, and will therefore be reviewed in the first section of this literature review (section 2.2). The influence of fatigue on both performance and injury risk in soccer has been well documented; driving the development of SSEP's designed to replicate the physical demands of match-play. Section 2.3 will therefore review previous free-running and treadmill-based SSEP's. Thereafter the influence of fixture congestion on performance and injury risk will be reviewed (Section 2.4). The final section of this literature review (Section 2.5) will focus on the time course of recovery following the completion of soccer match-play, before addressing potential methods to artificially speed up the natural time course of recovery.

2.2 PHYSICAL DEMANDS OF SOCCER MATCH-PLAY

Soccer is a team sport characterised by a self-paced, irregular, multi-directional and intermittent activity profile. The aforementioned characteristics result in extremely complex physical demands when compared to other modes of exercise (Greig et al., 2006). The self-paced nature of soccer match-play results in the completion of a sporadic and irregular activity profile, directly influenced by the context of the game. Nevertheless, as will be discussed in the subsequent sections of this chapter, the literature consistently agrees on a number of characteristics common to soccer match-play. The physical demands associated with soccer match-play have been elucidated from the completion of various match analysis techniques. These methods of match analysis, although different in their methodologies, essentially analyse the movement patterns of players during the completion of soccer match-play.

2.2.1 Activity profile with reference to fatigue

Match analysis literature has typically attempted to quantify the physical demand associated with soccer match-play based on the TD covered in a game. Mean values of 10-12 km have been reported for TD covered during the completion of a 90 min soccer match (Saltin, 1973; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988; Bangsbo et al., 1991; Bangsbo et al., 1994; Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al., 2014), with one study reporting a range of 5.97 km to 13.75 km (Di Salvo et al., 2007). This data therefore highlights the large variability associated with soccer match-play (Gregson et al., 2010). It has also been acknowledged that TD covered in the

second half of match-play is ~5-10% lower than that covered in the first half (Reilly and Thomas, 1976; Bangsbo et al., 1991; Mohr et al., 2003).

To further assess the physical demand of soccer match-play beyond the measure of TD covered, previous literature has quantified the activities performed across a number of locomotion categories (e.g. standing, walking, jogging, low speed running, backwards running, moderate speed running, high speed running, and sprinting) (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). The activity profile of elite (Italian 1st division) soccer players is presented in table 2.1 (Mohr et al., 2003).

Table 2.1 The activity profile of elite soccer players (adapted from Mohr et al., 2003)

Locomotion Category	Percentage of time	Frequency	Mean distance (m)	Total distance (m)	Mean duration (s)
Standing (0 km·hr ⁻¹)	19.5	163	0	0	7
Walking (4 km·hr ⁻¹)	41.8	379	10.7	4050.8	6.4
Jogging (8 km·hr ⁻¹)	16.7	316	6.7	2104.6	3
Low Speed Running (12 km·hr ⁻¹)	9.5	198	8.7	1714.3	2.6
Backwards Running (16 km·hr ⁻¹)	3.7	73	7.5	547.9	2.7
Moderate Speed Running (16 km·hr ⁻¹)	4.5	109	9.2	1000.0	2.2
High-Speed Running (21 km·hr ⁻¹)	2.8	69	10.5	724.5	2
Sprinting (30 km·hr ⁻¹)	1.4	39	16.7	649.7	3.5

The 10-12 km TD covered is characterised by ~1000-1500 changes in activity, with a change in activity occurring every 5-6s (Mohr et al., 2003; Reilly, 2003). The majority (~80-90%) of a soccer match is performed at submaximal locomotion speeds (Reilly and Thomas, 1976; Bangsbo, 1994; Rienzi et al., 2000; Mohr et al., 2003), with only ~7s of passive rest completed every 33s (Mohr et al., 2003). Players also typically complete a maximal sprint every 90-240s during match-play, with other HI efforts being completed every 30-60 s (Reilly and Thomas, 1976; Strudwick et al., 2002). A typical sprint in soccer

has been observed to last ~2-7s (Bangsbo et al., 1991; Stølen et al., 2005, Mohr et al., 2003), with an average distance covered of ~17 m (Mohr et al., 2003).

It has previously been identified that the amount of sprinting (23%) and high-speed running (3%) is impaired in the second half of match-play, with the lowest values being observed in the final 15 mins (Mohr et al., 2003). Reductions in HI activity often occur concurrently with compensatory increases in LI running. Bangsbo and Mohr (2005) and Bradley et al., (2009), identified that the time required to recover from sprints is also considerably increased in the second half of match-play. In support of the observed reductions in physical performance, reductions in physiological measurements (e.g. blood lactate concentrations and heart rate) have also been observed in the second half of a soccer match (Ekblom, 1986; Ali and Farrally, 1991; Stølen et al., 2005). Barros et al., (2007) and Rampinini et al., (2009) both identified reductions in TD covered in the second half of match-play when compared to the first. Rampinini et al., (2007b), identified that physical performance in the second half of a match was dependent on the total amount of work performed in the first half. For example, players who covered less distance in the first half typically covered greater distances in the second half and vice versa.

In further support of a cumulative fatigue effect in soccer, it has also been identified that substitute players run at a higher intensity and cover greater distances when compared to their counterparts who have played for the whole match (Mohr et al., 2003). As previously discussed in chapter 1, cumulative fatigue may also be a risk factor for injury during the latter stages of play (Hawkins et al., 2001; Bradley et al., 2009; Ekstrand et al., 2011). It should however be acknowledged that the aforementioned changes in physical performance may be influenced by contextual factors. In an attempt to control for contextual factors, Aldous et al., (2014) utilised non-motorised SSEP to assess changes in physical performance during the completion of soccer-specific exercise. The authors identified that physical performance was impaired as a function of exercise duration, thus suggesting a fatigue induced reduction in physical capacity. Future research is therefore required to identify the mechanisms responsible for these observed reductions in physical capacity.

In addition to the cumulative fatigue response described previously, Mohr et al., (2003) also identified that periods of temporary fatigue may also occur during a match. Temporary fatigue describes the observed below average reduction in activity observed following a period of HI activity. Mohr et al., (2003) and Bradley et al., (2009) identified reductions in HI running of 12 and 6% respectively immediately following the most intense period of

activity. Krstrup et al., (2006b) also identified periods of temporary fatigue by assessing sprint performance immediately following an intense period of activity in the first half and following each half of match-play. The authors identified a reduction in sprint performance immediately following the completion of the intense period of activity, but recovery of sprint performance by half-time (HT).

Previous time motion analysis literature has typically only reported TD covered, and the frequency, mean, and total duration of different locomotion categories (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). As such, this literature has often lacked some important detail in relation to the activity profile of soccer match-play. Bloomfield, et al., (2007) quantified the physical demands of English FA premier league soccer players. A “purposeful movement” (PM) was recognised as a movement; in possession of the ball, evading opponents in order to become available to receive the ball, supporting team mates in possession of the ball, competing for the ball, tracking and channelling opponents who either have or will have possession of the ball, and also technical and tactical positioning movements. As depicted in tables 2.2 and 2.3, Bloomfield and colleagues identified that these PM’s were executed across a range of locomotion categories and in a number of directions. These data suggest that the majority of PM’s (80%) were completed at low intensities, with 76.3% of all PM’s performed directly forwards, directly backwards, or in no specific direction.

Table 2.2 The percentage of total time spent in each locomotion category whilst performing PM’s (adapted from Bloomfield et al. 2007)

Locomotion Category	% of total time
Standing	4.6
Walking	14.2
Jogging	28.1
Running	11.1
Sprinting	9.9
Shuffling	18.1
Skiping	9.3

Table 2.3 The direction in which the PM's were executed (adapted from Bloomfield et al. 2007).

Direction	Percentage of total movements
Directly Forwards	48.7
Directly Backwards	7
Lateral Left	4.5
Lateral Right	3.9
Forward Diagonal Left	4.6
Forward Diagonal Right	5
No direction	20.6

Bloomfield et al., (2007) also quantified the frequency of turning and swerving performed during a match, with ~8 per minute (727 ± 203) during the completion of an elite 90min soccer match. The authors also identified that ~84% of all turns and swerves are performed 0-90° right or left. The data presented by Bloomfield et al., (2007) appears to suggest that the majority of soccer match-play is performed in a relatively linear manner with only a small number of changes of direction (COD) occurring during a match. Although the completion of utility movements and COD have been shown to increase the physiological demand to exercise (Buchheit et al., 2010; Buchheit et al., 2011; Buglione and di Prampero, 2013; Akenhead et al., 2015), the frequency of these actions in soccer are relatively low, and therefore their effects on the physical response to match-play will be negligible.

As previously discussed, a large proportion of previous time-motion analysis studies have focussed on assessing the TD covered and the speeds and distances covered across a variety of locomotion categories (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). By profiling soccer performance purely based on these aforementioned measures, the energy expenditure and the mechanical demand associated with the completion of soccer match-play may be underestimated (Osgnach et al., 2010). In recent years, an increased importance has been placed on quantifying the acceleration and deceleration demands to match-play, with it being identified that even at low running speeds, movements with accelerations are more energetically demanding than constant velocity running (di Prampero et al., 2005; Osgnach et al., 2010). Recently increased

attention has been afforded to assessing the acceleration and deceleration demands of soccer match-play, with Global Positioning Systems (GPS) often being utilised to quantify these demands. Akenhead et al., (2013) identified that acceleration and decelerations capabilities may be compromised as a result of fatigue during the completion of soccer match-play. It has also been identified that 18% of TD covered is completed whilst accelerating or decelerating at $>1 \text{ m}\cdot\text{s}^{-2}$ (Akenhead et al., 2013). More recent research identified that during a completion of a 90 min soccer match ~93% of all accelerations and decelerations are completed between -2 and $+2 \text{ m}\cdot\text{s}^{-2}$, with only ~100 m per 15 min bout of match-play being completed above or below -2 and $+2 \text{ m}\cdot\text{s}^{-2}$. Furthermore, Terje et al., (*In Press*) identified that 12–16% of the total PlayerLoadTM (an arbitrary unit that is derived from three-dimensional measures of the instantaneous rate of change of acceleration; Barrett et al., 2014) was attributable to the high frequency of accelerations and decelerations completed during a soccer match.

The aforementioned literature has identified that the highly intermittent nature of soccer match-play results in a high frequency of accelerations and decelerations being performed across a match. However, it should be acknowledged that the majority of these accelerations and decelerations are completed at relatively low velocities. Nevertheless, as will be discussed in the subsequent sections of this literature review, SSEP's should be characterised by a highly intermittent activity profile in an attempt to better replicate the acceleration and deceleration demands of soccer. Failing to replicate the highly intermittent nature of soccer match-play may result in an invalid physical response.

2.2.2 Evolutions in the demands of soccer match-play

It has been suggested that soccer players and coaches often share a belief that there has been an increase in the physical demands of soccer match-play (Barnes et al., 2014). Evolutions in the demands of other intermittent team sports such as handball and Australian Rules football (ARF) have been previously observed (Norton et al., 1999; Bilge, 2012). Similarly, evolutions in the technical components of soccer match-play have also been identified (Wallace and Norton, 2013). It therefore seems feasible that the physical demands of soccer match-play may have also evolved over time.

As previously discussed in section 2.2.1, mean values of 10-12 km have been consistently reported for the TD covered during the completion of a 90 min soccer match (Saltin 1973; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988; Bangsbo et al., 1991; Bangsbo et al., 1994; Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al.,

2014). Acknowledging the differences in the measurement techniques used between studies, it appears that the mean values for TD covered during soccer match-play has remained relatively consistent over the past 32 years.

However, it has been suggested that TD covered is a poor indicator of match performance (Van Gool et al., 1988) because it comprises all running intensities. High intensity running performance has been shown to differentiate between different playing standards (Mohr et al., 2003) and may therefore offer an improved method of assessing evolutions in the demands of modern soccer. Mohr et al., (2003), Rampinini et al., (2007a), and Bradley et al., (2009) all assessed HI running performance during soccer match-play using thresholds of $> 15 \text{ km}\cdot\text{h}^{-1}$, $>14.4 \text{ km}\cdot\text{h}^{-1}$, and $>14.4 \text{ km}\cdot\text{h}^{-1}$ respectively. The mean distances covered at HI (2.43 to 2.53 km) were similar between the three studies (Mohr et al., 2003; Rampinini et al., 2007a; Bradley et al., 2009), thus suggesting that there has not been a change in the distances covered at HI over the 6 year period. Nonetheless, considerably higher variability was identified in the more recent literature, thus limiting the comparisons between studies. These data further reiterate that the demands of soccer match-play are susceptible to both between-match and between-subject variations (Stølen et al., 2005; Gregson et al., 2010; Rollo et al., 2014).

Research conducted by the Bangsbo et al., (1994) Mohr et al., 2003 both quantified notational match-play analysis of male Danish first division soccer players. Mohr et al., (2003) identified a similar TD covered, a 9.3% increase in the frequency of changes in locomotion, a 42.8% increase in the TD covered whilst walking, a 43.4% reduction in the TD covered at low speed running, a 26.2% reduction in distance covered at moderate and high speed running, and a 22.9% increase in the distance covered whilst sprinting. These data suggest a change in the way in which the TD covered is achieved during a match, with more modern soccer match-play being characterised by increased distances covered whilst sprinting, walking, and jogging. The data presented by Mohr et al., (2003) supports more contemporary observations (Spencer et al., 2004) which suggest that modern soccer is characterised by periods of repeated sprint activity, interspersed by LI periods of walking and jogging.

Barnes et al., (2014) assessed the evolutions in the physical and technical performance parameters in the EPL between 2006-2007 and 2012-2013. It was identified that HI running distance (+30%), number of actions (+50%), number of sprints (+80%), and sprint distance (+35%) were increased in the 2012-2013 season when compared to six seasons previously. This data further suggests a change in the activity profile associated with

modern soccer match-play, characterised by increased number of speed changes and increases in the frequency and distances covered at HI's and sprinting. With only small changes in TD covered, increases in the frequency and TD covered at higher running velocities must occur concurrently with compensatory reductions at lower running velocities, thus further suggesting an activity profile characterised by HI efforts interspersed with LI active and passive recovery.

Epidemiological research conducted in professional soccer between 1980 and 1989 (Ekstrand and Gillquist, 1983; Nielsen and Yde, 1989; Sandelin et al., 1985) identified that the most prevalent injuries were ankle and knee ligamentous injuries. In contrast, more recent research has identified that the most prevalent injuries in soccer are knee flexor (KF) strains (Hawkins et al., 2011; Woods et al., 2004; Ekstrand et al., 2011). The observed differences in injury prevalence between soccer players in the 1980's and modern day players may be attributable to a number of factors such as, but not limited to, evolutions in the methods used to condition contemporary players, potential improvements in playing surfaces, more stringent sanctions for dangerous tackles, evolutions in the activity profile associated with soccer match-play, and an increased frequency of matches. In support of the observed increased prevalence of KF injuries in contemporary soccer, Orchard et al., (2012) suggested that increased average player speed and increased player fatigue are both independent risk factors for KF strains.

The activity profile of competitive match-play provides a means of understanding the physical work requirements of soccer. However, it is also important to quantify the physiological response elicited from the completion of soccer match-play.

2.2.3 Physiological demands

Heart rate and oxygen consumption

The energy expended during a soccer match can be calculated from values of oxygen uptake ($\dot{V}O_2$); however, measuring $\dot{V}O_2$ in a match is impractical and prohibited (Ogushi et al., 1993; Stølen et al., 2005). Alternatively, heart rate (HR) measurements may be used to predict the level of energy expenditure via the HR- $\dot{V}O_2$ relationship. Although the HR- $\dot{V}O_2$ relationship may over estimate energy expenditure during soccer match-play due to changes in HR occurring in isolation to changes in $\dot{V}O_2$ (Stølen et al., 2005; Bangsbo et al., 2007; Bangsbo et al., 2006), a number of previous studies have supported that the HR- $\dot{V}O_2$ relationship is valid method of predicting energy expenditure during intermittent exercise (Bangsbo, 1994; Castagna et al., 2005).

Heart rate measurements provide an accurate measurement of the total circulatory load associated with match-play (Reilly, 1990; Kirkendall, 2000), expressed as a percentage of maximal HR (HR_{max}). The average HR during a game has been suggested to be ~ 170 $b \cdot min^{-1}$ (Bangsbo, 1994; Reilly, 2003) and approximately 80-90% of HR_{max} , with peak values being close to maximal (Reilly and Thomas, 1976; Bangsbo, 1994; Kirkendall, 2000; Reilly 2003; Krstrup et al., 2006b). Despite the periods of active and passive recovery associated with soccer match-play, HR rarely drops below 65% of HR_{max} (Reilly, 1990, Bangsbo, 1994). Consequently, it has been suggested (Ekblom, 1986; Bangsbo 1994; Kirkendall, 2000; Stølen et al., 2005; Mohr et al., 2004) that the aerobic requirement associated with soccer match play is ~ 70 -75% of a player's maximal oxygen consumption ($\dot{V}O_{2max}$). The maximal aerobic capacity of adult male professional soccer players has been reported to range between ~ 50 -68 $ml \cdot kg^{-1} \cdot min^{-1}$ (Wisløff et al., 2004; Abt and Lovell, 2009; Sporis et al., 2009; Magalhães et al., 2010; Owen et al., 2011; Ziogas et al., 2011), and as such, average $\dot{V}O_2$ during soccer match-play has been shown to range between ~ 35 -48 $ml \cdot kg^{-1} \cdot min^{-1}$.

Blood lactate

The HI activity and often the most decisive actions during soccer match-play rely on high anaerobic-energy turnover (Stølen et al., 2005). Blood lactate (BLa) measurements can be utilised to quantify the anaerobic contribution to metabolism (Reilly 1990). Mean BLa concentrations have been identified between 2-10 $mmol \cdot L^{-1}$, with peak concentrations above 12 $mmol \cdot L^{-1}$ (Ågnevik, 1970; Bangsbo, 1994; Ekblom, 1986 and Krstrup et al. 2006b). Krstrup et al., (2006b) and Ispirlidis et al., (2008) both identified BLa concentrations of ~ 4 -4.5 $mmol \cdot L^{-1}$ following the completion of practice soccer matches. Blood lactate measurements are affected by between-match variability and are largely effected by the intensity of activity immediately prior to data collection (Krstrup and Bangsbo 2001; Stølen et al., 2015). High BLa concentrations (Ågnevik, 1970; Bangsbo, 1994; Ekblom, 1986 and Krstrup et al. 2006b) are a result of continued repeated HI activity; however, periods of LI active and passive recovery allow active removal of the BLa. Krstrup et al., (2006b) identified net BLa clearance rates of 0.1 $mmol \cdot L^{-1} \cdot min^{-1}$ in semi-professional soccer players during periods of passive rest. The intermittent nature of soccer produces different turnover rates of muscle and BLa. The periods of LI running allow muscle lactate to be cleared at a significantly greater rate than BLa. This may result in higher lactate concentrations in the blood than is actually present in the muscle (Bangsbo et al., 2006). Stølen et al., (2005) identified 40-50% higher BLa concentrations

in elite players when compared to their non-elite counterparts. This data may be related to the higher frequency of HI efforts performed by elite players when compared to non-elite players (Mohr et al., 2003). Irrespective of playing standard, BLa concentrations have been shown to be lower in the second half of match-play (Stølen et al., 2005). This observation occurs concurrently with fatigue induced reductions in work rate observed towards the latter stages of match-play (Mohr et al., 2003; Bangsbo and Mohr, 2005; Barros et al., 2007; Di Salvo et al., 2007; Rampinini et al., 2009), and may be indicative of reduced glycogen availability and increased amount of LI running in an attempt to dissipate BLa. Increased concentrations of BLa also result in elevated hydrogen ion concentrations and subsequent reductions in muscle potential hydrogen (pH). Krstrup et al., (2006b) identified temporary decreases in muscle pH following intense periods of activity in both the first and second half of match-play; however, muscle pH was not significantly different post-match when compared to pre-match. These results therefore suggest that alterations in muscle pH do not seem to be related to post-match fatigue.

Substrate depletion

Krstrup et al., (2006b) identified that reductions in performance may be related to insufficient energy availability in the working muscles. Adenosine triphosphate (ATP) must be produced via both aerobic and anaerobic processes to allow for muscle contractions to occur. Due to the highly intermittent and sporadic nature of soccer match-play, it is difficult to identify as to what extent the different aerobic and anaerobic pathways are utilised to produce energy during soccer match-play.

The HI bouts of activity during a soccer match may result in the breakdown of phosphocreatine (PCr). It has been identified that reductions in PCr result in increased concentrations of potassium within the muscle interstitium, thus potentially contributing to the development of temporary fatigue (Krstrup et al., 2006b). It has been identified that post-trial concentrations of PCr are significantly reduced by ~10% when compared to pre-exercise (Krstrup et al., 2006). The authors also identified lower PCr concentrations following an intense period of activity in the second half of a match when compared to the first, thus suggesting a gradual reduction in PCr concentrations as a function of exercise duration. The data reported by Krstrup et al., (2006b) identified that reductions in PCr concentrations can occur temporarily during a match; however, these concentrations are quickly replenished. The nature of soccer match-play makes it difficult to measure PCr during a match and therefore measurements are usually taken during the HT interval and/or post-match. However, the timing of these measurements allows for some re-synthesis and,

thus, immediately post-exercise PCr concentrations may actually be approximately 60% of resting levels (Krustrup et al. 2006b). The aforementioned literature suggests that PCr concentrations are quickly recovered both during and following soccer match-play.

Muscle glycogen concentrations have been identified to be 85% depleted following the completion of soccer match-play, with glycogen stores being 65% depleted following the completion of the first half (Kirkendall, 2000). Saltin (1973) identified that the players who started a match with low glycogen stores were almost fully depleted in glycogen by the HT interval and covered 25% less distance than players with normal pre-match muscle glycogen levels. An interesting finding by Saltin (1973) was that the players with depleted glycogen stores, on average completed half of the TD running and only 15% of the match at HI, whereas players with normal pre-exercise glycogen levels were able to cover 27% of the match walking and 24% of the match sprinting. A more contemporary study by Krustrup et al., (2006b) attempted to assess the rate of muscle glycogen depletion in soccer players who were deemed to have 73% of all muscle fibres 'full' with glycogen prior to the completion of the match. The authors identified that post-match muscle glycogen concentrations were 46% lower than pre-match levels, with 11% of all fibres being fully depleted and a further 36% being almost fully depleted. It is evident that not all glycogen stores were fully depleted post-match, and therefore fatigue may be due to the depletion of glycogen in specific muscle fibres rather than total the total depletion of muscle glycogen (Krustrup et al., 2006b). The current data therefore suggests that glycogen availability may influence the observed reductions in physical performance observed towards the latter stages of match-play (Mohr et al., 2003; Bangsbo and Mohr, 2005; Barros et al., 2007; Di Salvo et al., 2007; Rampinini et al., 2009)

During the completion of soccer match-play, free fatty acids (FFA) concentrations in the blood are increased, and this increase is markedly greater during the second half (Bangsbo 1994; Krustrup et al. 2006b). The frequent periods of passive recovery and LI exercise elicit increased blood flow; subsequently increasing FFA concentrations in the blood and ultimately an increase in the oxidation and uptake of FFA by the working muscles. This increased utilisation of muscle triglycerides and the release of FFA from the adipose tissue occur as a compensatory mechanism for the gradual reduction in muscle glycogen concentrations as soccer match-play progresses (Krustrup et al., 2006).

The cumulative reductions in performance observed during soccer match-play appear to be influenced by physiological fatigue. Periods of temporary and cumulative physiological fatigue may also influence the rate of mechanical fatigue, and thus influence injury risk

(Ekstrand et al., 2011). It has previously been suggested that increases in peripheral biomarkers influence type III and IV nerve afferents, thus initiating temporary and cumulative reductions in central motor output (Gandevia, 2001; Ammann, 2011; Sidhu et al., 2013). Reductions in central motor output will result in impaired muscular function, and inevitably result in a player being at an increased risk of injury.

2.2.4 Mechanical demands

The physiological response to soccer match-play has been extensively researched; however, the mechanical response associated with soccer match-play has not received as much consideration. Due to a lack of available literature, the current section will therefore review previous literature that has assessed the mechanical response to both soccer match-play and SSEP's. However, as will be discussed in the subsequent sections of this literature review, the mechanical data recorded from the SSEP's should be treated with caution due to potential issues associated with the validity of some of these protocols.

Muscular strength

The ability to sustain muscular strength during the completion of a match is pre requisite for successful performance in soccer. Fatigue induced reductions in muscular strength have implications for both performance (Rahnama et al., 2003) and injury risk (Hawkins et al., 2001; Ekstrand et al., 2011). Previous research has, therefore, attempted to assess the cumulative fatigue induced reductions in muscular strength following the completion of soccer match-play (Andersson et al., 2008; Ascensão et al., 2008).

Ascensão et al., (2008) recruited sixteen male soccer players to assess the time course of recovery associated with a number of lower limb performance tasks. The authors identified that concentric knee extensor (KE) and KF peak torque (PT) were significantly reduced by 10 and 15% respectively immediately post-match. Andersson et al., (2008) assessed the recovery of a number of lower limb performance measures following the completion of an elite female soccer match and identified reductions in concentric KF and KE PT of ~9 and 7% respectively. The data reported by both Ascensão et al., (2008) and Andersson et al., (2008) showed reductions in concentric muscular strength following the completion of soccer match-play, with these reductions occurring concurrently with increases in creatine kinase (CK). These data therefore suggests that these measures may both be influenced by exercise induced muscle damage (EIMD). Howatson and van Someren (2008) stated that EIMD occurs due to a mechanical disruption of the muscle fibre, as characterised by a loss of z-disc integrity and myofilament disorganisation. The severity of muscle damage is specific to the preceding bout of exercise and is characterised by a temporary decrease in

muscle function, increased muscle soreness (MS), increased swelling of the involved muscle groups, and increased intracellular proteins in the blood (Howatson and Van Someren, 2008).

It has also been suggested that a secondary muscle damage response may also occur post exercise due to changes in excitation-contraction coupling and increased inflammatory processes (Howatson et al., 2010). When both ATP and PCr are rapidly broken down during exercise, increased levels of magnesium ions, adenosine diphosphate (ADP), and inorganic phosphate are produced. Reductions in ATP concentrations and increased inorganic phosphate and magnesium ions result in an impaired release of calcium ions from the sarcoplasmic reticulum, subsequent reductions in force productions (Allen and Westerblad, 2001; Dutka and Lamb, 2004), and reduced energy release from the the breakdown of ATP (Sahlin et al., 1998). Similarly, increased concentrations of ADP can affect the contractile properties of the muscle and reduce the calcium uptake back into the sarcoplasmic reticulum. Increased concentrations of ADP therefore negatively influence the force production of a muscle, and impair the ability of the muscle to relax (MacDonald and Stephenson, 2004).

Although the assessment of concentric KF PT provides a measure of reductions in muscular strength, it could be argued that it does not offer a functionally relevant assessment of muscle strength. Previous epidemiological research has identified that KF injuries are the most prevalent injuries in soccer (Hawkins et al., 2011; Woods et al., 2004; Ekstrand et al., 2011). It has been identified that KF strain injury is highest during the terminal swing phase of a sprint cycle when the KF musculature is required to eccentrically contract to resist the rapid knee extension elicited from the KE musculature (Heidersheit et al., 2005; Thelan et al., 2005; Crosier, et al., 2008; Schache et al., 2009). The physical demands of running, the anatomy of the hamstring musculature, and a number of modifiable and non-modifiable risk factors such as, but not limited to, fatigue, age, previous injury, ethnicity, flexibility, bilateral and ipsilateral strength imbalances, and previous KF injuries have all been linked to the occurrence and/or reoccurrence of KF injuries (Opar, Williams, and Shield, 2012). The assessment of eccentric KF PT may therefore offer a more relevant assessment of muscular fatigue and a marker of KF injury risk during the completion of soccer-specific activity.

Rahnama et al., (2003) utilised a treadmill-based SSEP (Drust, et al., 2000b) to assess changes in concentric and eccentric KE and KF PT across a number of angular velocities (Concentric: 60, 120 and 300 deg·s⁻¹; Eccentric: 120 deg·s⁻¹). Isokinetic data was recorded

pre-trial, during the HT interval, and immediately post-trial. It was identified that for all angular velocities, concentric and eccentric KE and KF PT were higher pre-trial when compared to HT, and higher at HT when compared to post-trial. These data support previous observations of injury risk in the second half of match-play, and in particular towards the latter stages of the second half (Ekstrand et al., 2011). However, Rahnema and colleagues utilised an amateur population and therefore these results may not be indicative of more elite players. Angular velocities as high as 600-700 deg·s⁻¹ have been recorded during maximal sprinting (Marshall et al., 2014), as such the angular velocities (120 deg·s⁻¹) utilised by Rahnema et al., (2003) for the eccentric contractions were not functionally relevant. Nevertheless, there are benefits associated with recording isokinetic data at low angular velocities, such as the ability to collect data over a more prolonged isokinetic period and the increased reliability associated with this data.

In an advancement of the work conducted by Rahnema et al., (2003), Greig (2008) measured lower limb isokinetic dynamometry every 15 min during the completion of a treadmill-based SSEP. Greig (2008) recruited professional players to assess the time course of changes in concentric KE PT, concentric KF PT, and eccentric KF PT recorded at a range of angular velocities (60, 180, and 300 deg·s⁻¹). By completing testing at a range of isokinetic velocities a better appreciation of the force-velocity relationship of a muscle can be identified. Similarly, more functionally relevant testing speeds can be utilised. In contrast to previous match-play observations (Ascensão et al., 2008; Andersson et al., 2008), it was identified that irrespective of testing speed, both concentric KE and KF PT were maintained across the protocol. These data may be indicative of the specific participant group and/or differences in the activity profile associated with the SSEP when compared to match-play. Greig (2008) did, however, identify that eccentric KF PT data recorded at 'moderate' (180 deg·s⁻¹) and 'fast' (300 deg·s⁻¹) angular velocities was significantly higher at rest and following the first 15mins when compared to the data recorded immediately after HT and immediately post-trial. Significantly lower fast eccentric KF PT data was also recorded at the end of the first half (~17%) and at 75mins (~14%) when compared to resting values. Greig (2008) also observed that the reductions in eccentric KF PT significantly impaired dynamic strength ratios (Eccentric KF: Concentric KE) at both 180 and 300 deg·s⁻¹. Similar to Rahnema et al., (2003), the data presented by Greig supports the increased KF injuries observed towards the latter stages of soccer match-play (Hawkins et al., 2001; Ekstrand et al., 2011). These data also suggest that the greatest reduction in fast and moderate speed eccentric KF PT occurs during the first 45 mins of soccer-specific activity. In support of this, Marshall et al., (2014) identified

significant reductions in eccentric KF PT following the first 15mins of a SSEP (Small et al., 2009).

Small et al., (2010) utilised a free running SSEP (Small et al., 2009) to assess a number of lower limb isokinetic measures in semi-professional soccer players. Concentric KF PT, concentric KE PT, eccentric KF PT, dynamic strength ratios, and angles of peak torque (APT) were recorded at rest, at the beginning of the HT period, and immediately after the completion of the protocol. Similar to Rahnema et al., (2003), a limitation of the Small study was that the eccentric testing was completed at a low angular velocity ($120 \text{ deg}\cdot\text{s}^{-1}$). In support of the data presented by Greig (2008), the authors identified that concentric KF and KE PT was not significantly affected by the SSEP; however, eccentric KF PT was significantly lower at HT (~12%) and at the end of the protocol (~17%) when compared to resting values. A similar pre- to post-trial reduction of ~18% was also observed with a similar participant group following the completion of an alternative free-running based SSEP (Cohen et al., 2015).

Small et al., (2010) also identified changes in the APT data, with eccentric KF APT being significantly higher at both HT (23.2%) and at the end of the protocol (26.2%) when compared to resting values. In contrast, significantly lower concentric KF and KE APT data was recorded at HT and at the end of the protocol. It has previously been identified that fatigue elicits reductions in maximum knee flexion and knee extension angle during each running stride (Pinniger et al., 2000; Small et al., 2009), indicative of a reduced KF maximum elongation capacity (Hannon et al., 2005; Small et al., 2009). The increases in eccentric KF APT observed by Small et al., (2010) are therefore indicative of shorter muscle lengths and subsequent reductions in maximum elongation capacity. Reductions in a muscles maximum elongation capacity would result in the KF musculature being at a higher risk of injury when the muscle is required to operate in a more lengthened position, and may help to explain the increased risk of KF strain injuries observed towards the latter stages of match-play (Ekstrand et al., 2011). The observed pre- to post-trial changes in eccentric KF APT data identified by Small et al., (2010) have recently been supported by contemporary research using a similar participant group and free-running based SSEP's (Cohen et al., 2015; Coratella, et al., 2015).

Surface electromyography

Surface electromyography (EMG) has been used to compare muscle activity among different sports movements and is useful in evaluating changes in muscle activity as a result of fatigue (Rahnema et al., 2006). It is difficult to assess muscle activity during a

competitive soccer match due to both restrictions on data collection and practical difficulties associated with the data collection. The majority of EMG literature (Greig et al., 2000; Rahnama et al., 2006; Marshall et al., 2014) has therefore been completed using SSEP's.

Rahnama et al., (2006) attempted to assess the muscle activity of lower limb muscles during the completion of a treadmill-based SSEP (Drust et al., 2000b). Ten amateur soccer players were recruited to perform both a control and experimental trial. The control trial was characterised by periods of passive rest between EMG measurement points, whereas the experimental trial comprised the completion of the SSEP. Surface electromyography was recorded for the rectus femoris (RF), bicep femoris (BF), tibialis anterior (TA), and gastrocnemius (GC) muscles of the dominant leg (preferred kicking leg) at rest, at HT, and immediately after the completion of the 90 min protocol. The EMG activity was recorded over for a three minute period of treadmill based running incorporating 10 complete gait cycles at speeds of 6, 12, 15, and 21 km·h⁻¹. The EMG data was initially filtered before the root mean square (RMS) of the EMG signal was obtained over the 10 gait cycles at each speed and measurement point. The authors identified that EMG activity increased significantly between speeds 6-12, 12-15, and 15-21 km·h⁻¹ for all muscles and for both trials. The authors also identified that EMG activity of the RF, BF, and TA significantly reduced as a function of exercise duration, with the fatigue effect being more marked at higher running velocities. These data therefore support the reductions in muscular strength observed towards the latter stages of SSEP's (Greig, 2008; Small et al., 2010; Cortella et al., 2015), and may support previous observation of increased injury risk (Ekstrand et al., 2011) and impaired performance (Mohr et al., 2003; Krstrup et al., 2006b; Bradley et al., 2009) towards the latter stages of soccer match-play. Similar to the fatigue response identified in muscular strength (Greig, 2008; Small et al., 2010), the data presented by Rahnama et al., (2006) identified that the greatest reduction in EMG activity occurs in the first half of the protocol, with only small further reductions occurring in the second half.

Similar to Rahnama et al., (2006), Greig et al., (2006) utilised a treadmill-based SSEP to assess fatigue induced changes in BF and RF EMG activity recorded from the dominant (kicking) leg. The EMG data was constrained to a standardised 30 s period of activity during each 15 min bout of the protocol. Each data collection period encompassed a single maximal sprint effort (25 km·h⁻¹). The EMG data was initially filtered and was analysed for both peak EMG (EMG_{pk}) and integrated EMG (iEMG). The analysis of EMG_{pk} provides a measure of the highest motor unit action potential identified in a muscle and is

capable of identifying instantaneous increases in muscle activation (Renshaw et al., 2010). Likewise, iEMG provides a measure of the area under the rectified EMG curve, thus providing a method of quantifying the 'Work-done' by a muscle over a specified time period (Renshaw et al., 2010). Greig et al., (2006) identified that the iEMG and EMG_{pk} data recorded for the BF and iEMG recorded for the RF did not significantly change as a function of exercise duration. However, the EMG_{pk} data recorded for the RF muscle was significantly higher in the final 15 min when compared to the first 30 min. The data presented by Greig et al., (2006), therefore contradicts the findings of Rahnema et al., (2006) by suggesting that the BF muscles are able to maintain muscle activity during the completion of prolonged intermittent activity. These data may be indicative of the low number of maximal sprints performed in the SSEP used by Greig et al., (2006), when compared to the prolonged periods of HI activity associated with the SSEP used by Rahnema et al., (2006). The limitations of the aforementioned SSEP's will be discussed in the subsequent sections of this literature review.

More recently Marshall et al., (2014) attempted to assess changes in KF muscle fatigue and central motor output during the completion of a SSEP. The authors recruited eight amateur soccer players and recorded maximal voluntary torque, rate of torque development, BF and medial hamstring (MH) voluntary activation, and BF and MH EMG amplitudes (EMG/M) following the completion of each 15 min bout of the protocol. The EMG/M data for the BF reduced as a function of exercise duration with the data recorded in the final 15min period of each half being significantly lower than the first 15 min period. The authors also identified that the reduction in BF EMG/M occurred concomitantly with the reductions in maximal torque. In support of previous observations (Rahnema et al., 2006; Greig et al., 2008; Small et al., 2010), the greatest reductions in BF muscle activity and maximal torque occurred in the first half of the SSEP. These data further support observations of increased KF injury risk during the latter stages of soccer match-play (Ekstrand et al., 2011).

Marshall et al., (2014) also identified that the fatigue response observed in the KF muscles was predominantly a result of reduced central motor output to the KF musculature. In support of this data, previous literature has identified that KE maximal voluntary contractions (MVC's) are most greatly influenced by central rather than peripheral fatigue following the completion of elite soccer match-play (Rampinini et al., 2011). It has also been identified that reductions in KE MVC's observed after repeat sprint activity is also predominantly a result of reductions in central motor output (Goodall et al., 2015).

Recently, in an attempt to quantify the physical demand associated with intermittent team sports, PlayerLoad™ data has been calculated from tri-axial accelerometer function of Catapult (Catapult Innovations, Scoresby, Australia) GPS devices (Boyd et al., 2011; Cormack et al., 2013; Scott et al., 2013; Barron et al., 2014; Cormack et al., 2014; Walker et al., *In Press*). The high sample rate (100 Hz) of the accelerometer in relation to the GPS (typically 5-10 Hz), and the capacity to measure movement in three planes, provides scope to further evaluate the mechanical response to exercise. Due to restrictions on data collection, previous literature assessing the PlayerLoad™ response to soccer match-play is limited.

Research conducted by Barron et al., (2014) attempted to assess the external load during youth football, focussing on PlayerLoad™ metrics. Data was collected from 38 youth outfield soccer players for eight full 90 min matches. The PlayerLoad™ data was quantified for tri-axial PlayerLoad™ (PL_{total}) as well as uni-axial PlayerLoad™ in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}), and vertical (PL_V) movement planes. All PlayerLoad™ data was pooled for playing position prior to analysis. The data presented by Barron et al., (2014) identified that the PlayerLoad™ metrics were sensitive enough to detect differences in the physical demand associated with different playing positions; however, a limitation of this study was that the PlayerLoad™ data was only quantified for a 90min bout of match-play. A second limitation was that the PlayerLoad™ data was not standardised for the different distances covered by each position. Further analysis of the data presented by Barron and colleagues identified that irrespective of position, the players covered ~8.5 km over a 90 min match. Standardised for distance covered, and irrespective of playing position, PL_{total}, PL_{ML}, PL_{AP}, and PL_V were ~100.25, 26.27, 29.48, and 44.98 a.u/km, respectively. The PL_{total} values reported by Barron et al., (2014), are slightly lower than the average PL_{total} values of ~129.1 and ~131.4 a.u/km recorded from elite youth soccer players during the completion of match-play and a free-running SSEP respectively (Barrett et al., 2013).

Cormack et al., (2013) attempted to assess the influence of neuromuscular fatigue on measures of PlayerLoad™. The study was conducted using 17 elite ARF players providing data from a total of 37 competitive matches. Baseline neuromuscular fatigue assessments (flight time: contraction time [FT: CT]) were recorded pre-season from the completion of a countermovement jump performed after the Yo-Yo Intermittent Recovery Test level 2 (Krustrup et al., 2006a). Neuromuscular fatigue assessments were then performed prior to

each competitive match to identify if the players performed the match in a fatigued (FT: CT score of <92% of baseline) or non-fatigued state. During each match the relative contributions of each uni-axial PlayerLoadTM measures to PL_{total} (PL_{ML}%, PL_{AP}%, and PL_V%) were quantified. The PL_{total} data was standardised per minute of match-play. In hierarchical order the mean relative contributions of PL_V%, PL_{AP}%, PL_{ML}% was ~44: 32: 24 and ~42: 35: 23 for the non-fatigued and fatigued players, respectively. These data therefore identify that fatigued players elicit a ~2% lower relative contribution of PL_V and a compensatory increase in PL_{AP} of ~3%. The data presented by Cormack et al., (2013) therefore identifies that PlayerLoadTM metrics are sensitive enough to detect fatigue induced changes in running technique and/or efficiency. Similar to Barron et al., (2014), Cormack and colleagues only quantified the PlayerLoadTM data for full matches. Future research should therefore consider assessing the time history of changes associated with the PlayerLoadTM measures recorded during the completion of soccer-specific activity.

2.2.5 Summary

Soccer match-play is characterised by an irregular and highly intermittent activity profile, with ~1000-1500 changes in locomotion occurring during the completion of a 90min match (Mohr et al., 2003; Reilly et al., 2003). Although the TD covered during the completion of a soccer match has not varied greatly over the past 32 years, there does appear to have been evolutions in the physical demands of the game. Contemporary soccer match-play appears to have evolved to now be characterised by a high frequency of HI actions which are interspersed with periods of LI active and passive recovery (Spencer et al., 2004; Barnes et al., 2014). The activity profile associated with soccer match-play is typically defined relative to a time base (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010), which has previously been used to aid the development of SSEP's.

This current section has also identified that soccer match-play elicits both temporary and cumulative physical fatigue (Mohr et al., 2003; Krstrup et al., 2006b; Bradley et al., 2009; Aldous et al., 2014), with reductions in performance being observed following the completion of HI bouts of activity, and also towards the latter stages of a match. Although these declines in performance may be attributable to physiological mechanisms, physiological fatigue does not appear to be sufficiently cumulative to influence the increase in injury risk observed towards the end of soccer match-play (Ekstrand et al., 2011). It therefore seems surprising that the mechanical demand to soccer match-play has

received considerably less consideration when compared to the physiological response. A greater understanding of the physical response to soccer-specific activity is therefore required.

2.3 SIMULATING THE PHYSICAL DEMANDS OF SOCCER MATCH-PLAY

Although soccer match-play offers high ecological validity, the nature of the game is such that it is often difficult or prohibited to determine physical stresses during the completion of a match (Rollo et al., 2014; Stølen et al., 2005). Similarly, matches are susceptible to contextual factors (Gregson et al., 2010; Rollo et al., 2014), thus resulting in difficulty to assess the effectiveness of interventions. Soccer-specific exercise protocols have therefore been developed in an attempt to replicate soccer match-play and gain a better understanding of the physical demands of soccer match-play. These SSEP's can be broadly categorised as treadmill-based or free-running protocols.

2.3.1 Free-running soccer-specific protocols

Free-running protocols are intuitively appealing, providing the opportunity for increased ecological validity in comparison with laboratory-based treadmill protocols. However, any simulation must be validated based on the input (distance covered, duration, and activity profile) and the output (physical response).

Bishop et al., (1999) recruited university standard soccer players to complete a protocol based on the activity profile of professional soccer (Bangsbo et al., 1991). The protocol comprised two 45 min bouts of intermittent activity, interspersed by a 15 min passive recovery period. Each 45 min period was sub-divided into three bouts of 14 mins, interspersed by a 1.5min period of passive recovery. The 14min exercise bout comprised seven 2 min circuits consisting of 50 m walking, 50 m backwards running, 25 m cruise running, 25 m maximal sprinting and 50 m dribbling.

The protocol presented by Bishop et al., (1999) was evaluated using the observation that jogging constituted a TD covered of 2 km (Bangsbo et al., 1991), equating to 48 m per 2 min circuit. However Bishop et al., (1999) did not justify the distance covered at any other speed. The distances covered at each locomotion category (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010) and the frequency of speed changes are not representative of match-play (Reilly and Thomas 1976; Bangsbo 1994; Mohr et al 2003; Di Salvo et al 2010). The average TD covered during the protocol was 9.7km; similar to that reported in notational analysis literature (Saltin, 1973; Withers et al., 1982; Ekblom

1986; Van Gool et al., 1988; Bangsbo et al., 1991; Bangsbo et al., 1994; Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al., 2014). With respect to the physiological response, Bishop et al., (1999) identified that the protocol provided a valid simulation of match-play. However, this claim was contradicted within the same study, because the cortisol response to the protocol was identified as not being representative of the response associated with match-play. Failing to accurately model the speed, duration, and frequency of each discrete bout of activity further limits the validity of the protocol in eliciting a physical response representative of match-play.

The Loughborough Intermittent Shuttle Test (LIST) was designed to replicate the activity profile associated with soccer match-play (Nicholas et al., 2000). The LIST comprised two distinct parts. Both parts of the LIST require the participants to complete a number of 20 m shuttles performed at alternating locomotion velocities. The first part of the LIST consists of the completion of five 15 min bouts of activity, each interspersed with 3mins of passive recovery. The 15min bouts of activity are based on the previous notational data (Reilly and Thomas 1976). During each of the 15 min exercise periods, participants are required to repeatedly perform a fixed velocity profile consisting of a number of alternating locomotion categories (4 x 20 m at a walking pace, 1 x 20 m at a maximal running speed, 4s of passive recovery, 3x 20 m at a velocity equivalent to 55% of predicted $\dot{V}O_{2max}$, and 3x 20 m at a velocity equivalent to 95% of predicted $\dot{V}O_{2max}$). The second part of the protocol consists of an open-ended period characterised by alternating 20m shuttles performed at running velocities equivalent to 55 and 95% of theoretical $\dot{V}O_{2max}$. This velocity profile is performed until the participant reaches volitional exhaustion, deemed the point where the participant is unable to successfully complete two consecutive shuttles (~10min).

Based on both the activity profile and the physiological response (HR, blood glucose, and BLa), Nicholas and colleagues claimed the LIST offered a successful simulation of match-play. Whilst TD covered (12.4 km) (Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al., 2014) and number of COD (624) (Bloomfield et al., 2007) are similar to match-play observations, the LIST is characterised by a disproportionate amount of time at HI (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). The LIST also requires the participants to complete distances covered at each locomotion category that

are not representative of match-play (Bangsbo et al., 1991; Mohr et al., 2003). Furthermore, the activity profile fails to reflect the irregular and highly intermittent nature of soccer (Reilly and Thomas, 1976; Bangsbo, 1994; Mohr et al., 2003; Di Salvo et al., 2010). The prolonged periods of HI exercise limit the evaluation of the physiological response. Moreover, the sample of seven male university soccer and rugby players fails to reflect the population from which the notational data was derived, thus further limiting the evaluation of the protocol as eliciting a valid physiological response. Furthermore, Magalhães et al., (2010) identified that the physiological responses to the LIST is significantly different to that elicited from actual match-play.

Similar to the LIST, the Soccer-specific Aerobic Field Test (SAFT⁹⁰, Small et al., 2009) was based on a shuttle run over a 20 m distance; however, the SAFT⁹⁰ protocol also incorporated four positioned poles for the subjects to navigate using utility movements. The protocol comprises of two 45 min halves, interspersed by a 15 min passive HT period. The SAFT⁹⁰ is based on time-motion analysis data obtained from English Championship match-play. The participants are required to navigate around the first pole (placed 2 m from the start line) by either backwards running or sidestepping, followed by forwards running through the course, navigating the middle three poles. An audio compact disc (CD) is used to provide verbal signals relating to the intensities and activities that should be performed. A standardised 15 min activity profile was developed and repeated six times to produce the 90 min period of activity. The total protocol comprised 1350 changes in direction and 1269 changes in velocity.

The overall TD covered, and the total distances covered at each locomotion category (Standing, walking, jogging, striding, and sprinting) during the SAFT⁹⁰ were similar to the notational data upon which the protocol was based (Small et al., 2009). However, the 20 m shuttle distance results in higher distances covered per bout of activity when compared to previous notational data (Mohr et al., 2003). Similarly, the total number of COD is almost double what has been previously reported during elite English match-play (Bloomfield et al., 2007). Raja Azidin et al., (2015) assessed the physiological (HR and rating of perceived exertion [RPE]) and mechanical (ability to perform a side cutting manoeuvre) response elicited from the SAFT⁹⁰ when compared to the same velocity profile performed on a treadmill. It was identified that the SAFT⁹⁰ resulted in an elevated physiological response when compared to the treadmill protocol; however, there was no difference in the mechanical fatigue response elicited from the two protocols. In support of previous observations (Buchheit et al., 2010; Buchheit et al., 2011; Buglione and di Prampero, 2013;

Akenhead et al., 2015), these data suggest that the physiological response associated with the SAFT⁹⁰ appears to be enhanced by the high frequency of COD, thus limiting the evaluation of the physiological response in comparison to match-play. The data reported by Raja Azidin et al., (2015) also suggests that the high frequency COD do not appear to elicit an increased mechanical fatigue when compared to treadmill-based running.

Similar to the circuit based protocol designed by Bishop et al., (1999), Williams et al., (2010) developed the 90 min Ball Sport Endurance and Sprint Test (BEAST₉₀). The BEAST₉₀ comprises two 45 min halves interspersed by a 15 min period of passive recovery. The participants are required to continuously complete repeated circuits for the duration of each half comprising sprinting, backwards jogging, walking, jogging/decelerating, and forward running at ~75% of maximum effort. The participants are also required to complete jumping and shooting tasks during each circuit. Williams et al., (2010) did not report the notational data upon which the BEAST₉₀ was based.

The TD covered (8.10 ± 0.45 km), average distance covered whilst walking (1.74 ± 0.10 km), and the average distance covered whilst jogging (2.26 ± 0.15 km) during the BEAST₉₀ were all lower than what has been previously reported in time motion analysis literature (Bangsbo et al., 1991; Rienzi et al., 2000; Mohr et al., 2003). The time spent stationary (~30mins) during the BEAST₉₀ was considerably higher than that reported during soccer match-play (Bangsbo et al., 1991; Mohr et al., 2003; Thatcher and Batterham, 2004). The BEAST₉₀ was also characterised by a disproportionate distance covered at moderate- to high-intensity running (3.27 ± 0.24 km) when compared to previous literature (Bangsbo et al., 1991; Mohr et al., 2003; Thatcher and Batterham, 2004). The velocity profile performed during the BEAST₉₀ protocol is therefore not representative of match-play. The disproportionate amount of HI running and the amateur status of the participants limit the evaluation of the physiological response.

Russell et al., (2011) developed a Soccer Match Simulation (SMS) similar to the LIST (Nicholas et al., 2000), but with the inclusion of passing, dribbling, shooting, backwards movements, lateral movements, increased jogging, and a HT period. Similar to the SAFT⁹⁰ (Small et al., 2009), the movements were controlled by audio signals from a CD. The SMS was completed as two periods of 45 min with a 15 min passive HT period interspersing the two periods of activity. Each 45 min period of the simulation comprised seven 4.5 min periods of intermittent activity. More specifically, each 4.5 min period comprised three repeated cycles of three 20 m walks, an alternating 20 m dribble test or a 15 m sprint, a 4s passive recovery period, five 20 m jogs at a speed corresponding to 40% of predicted

$\dot{V}O_{2max}$, one 20 m backwards jog at 40% of predicted $\dot{V}O_{2max}$, and two HI runs completed at 85% of predicted $\dot{V}O_{2max}$. A 1 min passing test and a 1min period of passive rest was performed after each bout of activity.

Based on both the activity profile and physiological response, Russell et al., (2011) claimed the SMS provided a valid simulation of soccer match-play. Although the TD covered (10.1km) (Saltin, 1973; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988 Bangsbo et al., 1991; Bangsbo et al., 1994 Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al., 2014) and number of on the ball movements and dribbles were similar to those reported in match-play (Bloomfield et al., 2007), the SMS is characterised by prolonged periods of passive recovery and distances covered at each locomotion category that are not representative of match-play (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). The low frequency of changes in locomotion (168 per 90 mins) fails to reflect the highly intermittent nature of soccer match-play (Reilly and Thomas, 1976; Bangsbo, 1994; Mohr et al., 2003; Di Salvo et al., 2010). The SMS can therefore not be regarded as a valid representation of match-play.

Bendiksen et al., (2012) developed the Copenhagen Soccer Test (CST) as a 2 x 45 min field test based on notational data collected during competitive matches (Mohr et al., 2003). It was stated that the movement patterns, the amount of HI running, the time with the ball, and the number of the number of headers, shots, and passes were all considered. To allow for the assessment of periods of temporary fatigue (Mohr et al., 2003; Krstrup et al., 2006b), the CST was sub-divided into 18 periods of 5 min. Each of the 5 min periods of activity comprised 152 m of walking ($\sim 6 \text{ km}\cdot\text{h}^{-1}$); 171 m of Jogging ($\sim 8 \text{ km}\cdot\text{h}^{-1}$); 69 m of low ($\sim 12 \text{ km}\cdot\text{h}^{-1}$), 41 m of moderate ($\sim 15 \text{ km}\cdot\text{h}^{-1}$) and 55m high speed running ($\sim 18 \text{ km}\cdot\text{h}^{-1}$); 2 x 20m sprinting ($\sim 6 \text{ km}\cdot\text{h}^{-1}$); 30 m backwards running ($\sim 8 \text{ km}\cdot\text{h}^{-1}$); and 23 m of backwards/sideways running ($\sim 8 \text{ km}\cdot\text{h}^{-1}$), respectively. It was also stated that each of the 5 min periods were either classified as low- (L), moderate- (M), or high-intensity (H). During the M periods the participants were required to complete an additional 20 m of moderate and 22 m of high speed running, whereas during the H periods the participants were required to complete an additional 60 m of moderate and 65 m of high speed running. Each half of the CST is completed in the order L-M-H-L-M-M-L-M-H. The TD covered over a 90 min test was therefore 11.29 km, with 3.28 km covered at high-intensity running,

and 0.72 km covered sprinting. The authors also assessed sprinting ability and shooting and passing performance pre-trial and immediately following each 5 min period of activity.

Bendiksen et al., (2012) validated the physiological response based on the response elicited by the same players in a competitive game, and identified that the CST replicated the physiological response. The distances covered at each locomotion category and the velocity profile was also identified as being valid when compared to the match-play data upon which the CST was based (Mohr et al., 2003). To further support the validity of the protocol, the CST also includes soccer-specific movements, frequent changes in exercise intensity, and ball handling (Mohr et al., 2003; Bloomfield et al., 2007; Andersson et al., 2008; Bradley et al., 2009). The CST appears to offer the most valid method of replicating soccer match-play when compared to the other free-running protocols reviewed in this section; however, the complicated design and the area required to complete the test limits its application.

Additional soccer-specific endurance tests have been developed around the activity profile of match-play, with the intent of testing physical capacity as opposed to replicating the demands of match-play. Rico-Sanz et al., (1999) designed a test which consisted of a number of 15m exhaustive shuttle runs at varying speeds. Performance was quantified as the duration of the test to a prescribed performance decrement or volitional failure. Bangsbo and Lindquist (1992) developed a soccer-specific intermittent field test of 16.5 min duration, comprising 40 bouts of multi-directional HI exercise of 15s, interspersed with 10s of LI running. Performance in this test is quantified as distance covered during the test. The most recent and arguably the most popular fitness tests are the Yo-Yo intermittent recovery test level 1 (Krustrup et al., 2003) and the Yo-Yo intermittent recovery test level 2 test (Krustrup et al., 2006a). These tests comprise the completion of two 20 m shuttles with a 10 second period of active recovery (controlled by audio signals from a CD). The time allowed to achieve the 2 x 20 m shuttles gradually reduces until the athlete is unable to maintain the speed. The level 1 test is designed to assess an athlete's endurance capacity and is characterised by a lower starting speed and more gradual changes in speed when compared to the level 2 test which is designed to assess the athlete's ability to complete repeated HI efforts. Whilst such exercise tests have their merits in conditioning, they are not designed to replicate the activity profile of match-play.

With the exception of the CST (Bendiksen et al., 2012), the free running protocols reviewed in this section all possess validation issues. The aforementioned protocols either

do not replicate the velocity profile of soccer match-play and/or have utilised the wrong participants to validate the protocols.

2.3.2 Treadmill-based protocols

Whilst free-running protocols might offer the opportunity for greater ecological validity, laboratory-based protocols offer far greater experimental control, manipulation and intervention.

Drust et al., (2000b) developed a treadmill-based SSEP, evaluated against both the locomotion categories (Reilly and Thomas, 1976) and the time spent at each locomotion category (Van Gool et al., 1988). The treadmill based protocol comprised two 22.5 min bouts of activity, thus representing one half of match-play. Each 22.5min bout consisted of 23 bouts of activity (6 walking, 6 jogging, 3 cruising, 8 sprinting). The two bouts were interspersed by a 71s passive recovery period, designed to replicate the total amount of time that players stand still for during each half of match-play. The structure of the exercise bouts were designed to replicate the sporadic distributions of velocity changes associated with soccer. To further replicate the structure of the velocity profile associated with match-play, periods of HI activity (cruising $15 \text{ km}\cdot\text{h}^{-1}$ and sprinting $21 \text{ km}\cdot\text{h}^{-1}$) were interspersed by periods of LI active recovery (walking $6 \text{ km}\cdot\text{h}^{-1}$ and jogging $12 \text{ km}\cdot\text{h}^{-1}$). The duration of each locomotion category was 35.3, 50.3, 51.4 and 10.5s for walking, jogging, cruising, and sprinting, respectively.

With regards to limitations, the SSEP presented by Drust et al., (2000b) incorporates an insufficient frequency of speed changes when compared to soccer match-play. It has been recognised that on average there are ~1000-1500 changes in velocity during the completion of a 90min soccer match (Reilly and Thomas, 1976; Bangsbo, 1994; Mohr et al., 2003; Di salvo et al., 2010). However, Drust et al. (2000b) only included a total of 46 discrete bouts during the treadmill protocol, equivalent to 92 for a 90 min match. Furthermore, the duration of each discrete bout (at all speeds) is excessive in relation to match-play data (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). Prolonged periods of activity will inevitably affect the physiological response. Drust et al (2000b) identified that average energy expenditure values identified during the protocol were similar to those proposed by Reilly (1990) with values of 70-75% of $\dot{V}\text{O}_{2\text{max}}$. The authors also identified that the HR response was similar to values reported by Van Gool et al. (1983). However this physiological comparison is not sufficient to validate the use of this protocol as an

accurate simulation of soccer match-play. The validity of the protocol is limited by the failure to accurately reflect the velocity profile and the highly intermittent nature of soccer match-play.

The same research group also developed a non-motorised treadmill protocol characterised by a 198 changes in activity (Drust et al., 2000a). The activity profile was based on data obtained by Drust et al (1998) using South American international players, quantifying the percentage of total time spent within each locomotion category. Although an improvement on the motorised treadmill protocol (Drust et al. 2000b), the low frequency of speed change limits the validity of non-motorised protocol in eliciting a valid physiological and biomechanical response. Clarke et al. (2012) proposed a modified version of this protocol. However, although this protocol was more intermittent than the previous protocols proposed by Drust et al. (2000b), the percentage of time in each movement category fails to accurately reflect notational data (Reilly and Thomas, 1976; Bangsbo, 1991; Bangsbo, 1994; Mohr et al., 2003; Barros et al., 2007; Di Salvo et al., 2007; Rey et al., 2010; Osgnach et al., 2010). For example, stationary periods were negated, and the relative time spent walking was reduced in favour of more time spent at the higher running speeds. Again, the structures of the protocol will inevitably influencing the physical response.

Abt et al. (1998) manipulated a feature of the treadmill design in developing a protocol which utilised changes in both the speed and incline of the treadmill. Jones and Doust (1996) used varying running speeds to recommend that an inclination of 1% was most representative of outdoor running at low velocities, with an incline close to 2% required for higher velocities ($18 \text{ km}\cdot\text{h}^{-1}$). Abt et al. (1998) proposed a unique solution in attempting to manipulate changes in running mechanics to govern differences between LI and HI running. The intensity, TD covered (11.6 km), and intermittent nature of the protocol were all similar to soccer match-play; however, the total duration of the protocol was only 61mins. Failing to represent the 90 min duration of match-play is a limiting factor when evaluating the physical response to exercise.

More recently, Greig et al., (2006) presented a protocol designed specifically to replicate the intermittent nature of match-play in relation to the duration of each discrete bout of activity, as prescribed by notational analysis (Bangsbo, 1994). The categories of locomotion included stationary, walking, jogging, cruising, and sprinting. The duration and frequency of each category were taken directly from notational analyses, and subdivided to create a 15 min protocol. Greig et al. (2006) stated that the aim of this

protocol was to more accurately replicate the high frequency of changes in activity associated with soccer match-play. Despite accurately reflecting the frequency of speed change (Reilly and Thomas, 1976; Bangsbo, 1994; Mohr et al. 2003; Di salvo et al., 2010), and therefore the intermittent nature of soccer, the physiological response was considerably lower than that observed during match-play (Bangsbo et al., 1991; Bangsbo 1994; Reilly 1993; Stølen et al., 2005; Krstrup et al., 2006b; Ispirlidis et al., 2008). The structure of the intermittent velocity profile will inevitably influence the physical response, and the arbitrary and ad hoc distribution of speed changes used by Greig et al., (2006) may not be truly reflective of match-play. Contemporary notational analyses suggest that HI efforts in team sports typically occur in ‘clusters’ (Spencer et al. 2004). By clustering the HI efforts, periods of temporary and cumulative fatigue may be induced, and a more valid physiological response may be elicited. The mechanical response to the treadmill protocol presented by Greig et al., (2006) was quantified using changes in EMG activity of specific lower limb musculature. However this data has not previously been collected during match-play, and thus evaluation is difficult.

It is also worth considering the potential differences in gait characteristics associated with treadmill and over-ground running and the implications this may have when comparing the physical response associated with a treadmill-based SSEP to that associated with soccer match-play. Research conducted by Van Caekenberghe and colleagues (2013) identified significant differences in kinetic and kinematic measures recorded from 10 active healthy males accelerating on a treadmill when compared to over ground running. Whereas Riley et al., (2008) and Fellin et al., (2010) both identified comparable kinematic trajectories of treadmill running gait when compared to over ground running gait in healthy populations. It has previously been suggested that the completion of an adequate familiarisation, the use of a well calibrated and constant speed treadmill belt, and the use of a treadmill belt that is sufficiently wide and long will reduce the observed differences in running kinematics between over ground and treadmill running (Riley et al., 2008).

2.3.3 Summary

Soccer has a characteristic intermittent and irregular activity profile, with Drust et al., (2000b) identifying that it is the intermittent nature of soccer that increases the physiological demands. Previous SSEP’s have previously been validated based on the physiological response to the protocol; however, a large number of previous SSEP’s are typically characterised by disproportionately large contributions of HI activity in an attempt to elicit a favourable physiological response (Bishop et al., 1999; Drust, Reilly,

and Cable. 2000; Nicholas et al., 2000; Williams et al., 2010; Russell et al., 2011). Validation of SSEP on the physiological response is not appropriate given the high injury incidence observed towards the latter stages of match-play. To evaluate the validity of an SSEP designed to simulate intermittent soccer match-play, both the activity profile and the physical response must be considered. The physical response should be further sub-divided into the physiological and mechanical response.

If the intermittent nature of the activity profile is the most influential factor on the physiological response to match-play, then the primary aim of any SSEP's should be to replicate the intermittent nature of the activity profile. However when the intermittent profile has been modelled more accurately (Greig et al., 2006), the physiological response is lower than that observed in match-play (Bangsbo et al., 1991; Bangsbo 1994; Reilly 1993; Stølen et al., 2005; Krstrup et al., 2006b; Ispirlidis et al., 2008). As previously discussed, future SSEP's could potentially cluster the HI efforts in an attempt to elicit a favourable physical response without invalidating the highly intermittent nature of the velocity profile. The development of a protocol that achieves a balance of biomechanical integrity in the frequency of speed change, and the physiological response to exercise, will enable future research concerned with the physical response to intermittent exercise.

2.4 FIXTURE CONGESTION IN SOCCER

According to Strudwick (2012) modern soccer players should possess the capacity to complete a high number of matches (50-60) per season, with Dupont et al., (2010) acknowledging that the most successful teams at any level are often required to compete in the highest number of matches. The high frequency of matches associated with modern soccer (Mohr et al., 2003; Dupont et al., 2010; Strudwick 2012; Nédélec et al., 2013) results in players having to play with only two to three days recovery between successive matches (Dupont et al., 2010; Rollo et al., 2014; Carling et al., 2015; Dellal et al., 2015). The completion of successive matches with limited recovery has implications for both performance and injury risk.

2.4.1 *Physical performance*

Previous fixture congestion literature has attempted to assess changes in physical performance across two successive matches (Dupont et al., 2010; Rey et al., 2010; Lago-Peñas et al., 2011; Dajaoui et al., 2013; Rollo et al., 2014), three successive matches (Odetoyinbo et al., 2007; Carling and Dupont, 2011; Folgado et al., 2015), and more

prolonged periods incorporating six-seven matches (Carling et al., 2012; Dellal et al., 2015).

Dupont et al., (2010), Lago- Peñas et al., (2011) and Dajaoui et al., (2013) all attempted to assess the influence of one vs. two matches per week on the physical performance of elite soccer players. Total distance covered and distances covered across a range of locomotion categories were used to quantify physical performance. All three studies identified that there were no differences in the TD covered or the distances cover at any of the speed thresholds when comparing two vs. one match per week. This data therefore suggests that two matches can be performed over a seven day period without any changes in physical performance.

Rollo et al., (2014) also attempted to assess the effect of one vs. two games a week on physical and subjective scores of sub elite soccer players. The authors recruited thirty players from the same squad to assess the influence of playing one ($N= 15$) or two games ($N=15$) a week over a six week period. Rather than assessing within-match measures of physical performance, Rollo and colleagues assessed countermovement jump performance, 10 and 20m sprint times, performance in the Yo-Yo intermittent recovery test (Krustrup et al., 2003), and a recovery stress questionnaire at weeks 0, 3, and 6. The measures recorded at weeks three and six were recorded 48 h post-match. To ensure that the results were not affected by differences in training load, both groups performed the same two weekly training sessions. The authors identified no significant differences for any of the measures recorded at 3 weeks, but did identify significantly lower Yo-Yo and countermovement jump performance and higher 10 and 20m sprint times for the two game group at week six. These data suggests that laboratory based measures of physical performance may be able to detect fatigue induced changes during periods of fixture congestion.

Rey et al., (2010) attempted to assess the influence of two games performed over a three day period on the activity profiles of forty-two professional Spanish soccer players. Total distance covered, frequency of HI efforts, recovery time, mean speed, peak speed, and distances covered over a range of locomotion categories were used to quantify physical performance. The authors identified no significant differences in any of the performance measures recorded across the two trials, thus suggesting that the activity profile of elite soccer players does not appear to be influenced by the short recovery time between matches. In support of the observations made by Rey et al., (2010), Andersson et al., (2008) identified no significant differences in the amount of HI distance covered in elite female soccer matches performed 72h after the completion of an initial match.

Odetoyinbo et al., (2007), Carling and Dupont (2011), and Folgado et al., (2015) attempted to assess the physical response to three successive elite soccer matches performed over a six-seven day period. All studies reported no differences in the TD covered and distances covered at high speeds across the successive matches. Folgado et al., (2015) also identified no differences in the distances covered across any of the locomotion categories across the successive trials. Odetoyinbo et al., (2007) identified that the distance covered and duration of walking, the distance covered at HI whilst in possession of the ball, and distances covered at HI when the ball was out of play were all significantly lower in the third game when compared to the first. These data suggest TD covered and overall HI running distance is not significantly impaired when three matches are played over seven days; however, when three matches are performed over six days players may potentially alter their activity profiles in an attempt to reduce the volume of activity performed. It is however not known if these observed differences are a result of contextual factors or reduced physical capacity. The first two matches in the Odetoyinbo study were interspersed with 48 h recovery, whereas each of the matches in the Carling and Dupont (2010) and Folgado et al., (2015) studies was interspersed by 72h of recovery. It therefore seems feasible that the reduced recovery time associated with the first two matches in the Odetoyinbo study may have elicited the observed fatigue response identified in the third match.

Studies conducted by Carling et al., (2012) and Dellal et al., (2015) both assessed the physical response to a period of prolonged fixture congestion (six-eight games performed over eighteen-twenty-six days) in elite French soccer. In both studies, the data collected during the periods of fixture congestion were compared to that identified during a non-congested schedule. Total distance covered and the distances covered across a range of locomotion categories were recorded to quantify physical performance. Dellal and colleagues identified no significant differences in any of the physical performance measures recorded across the six games associated with the periods of fixture congestion, and no significant differences between the non-congested and congested periods. In contrast, Carling and colleagues identified that distances covered at light intensities and TD covered differed across the successive matches. In support of the study conducted by Dellal et al., (2015), Carling and colleagues identified that there were no observed differences in the distances covered at moderate and HI across the successive matches. The differences observed in the data presented by Carling et al., (2012) may be related to the limitations associated with this study. For example, data collection was not only restricted to outfield players, only six players took part in every match, and only one outfield player

completed every game. In contrast, in the study conducted by Dellal and colleagues, all players had to complete a minimum of 75 mins in each of the successive matches to be included in the data collection, and only outfield players were included in the analysis. Both studies do, however, identify that moderate and HI running performance does not appear to be impaired during a period of prolonged fixture congestion.

2.4.2 Injury risk

As previously discussed, Dupont et al., (2010) attempted to assess the physical response associated with two vs. one soccer match performed across a week. Dupont and colleagues also prospectively recorded injury data for time loss injuries in relation to the number of matches performed per week. Injury rates were shown to be significantly higher when players played two matches per week when compared to one (25.6 vs. 4.1 injuries per 100h of exposure). The authors also identified that considerably more thigh (32 vs. 15) and ankle injuries (15 vs. 6) were observed when two matches were performed in a week, with considerably higher sprains and ligamentous injuries (24 vs. 10) and muscle ruptures, tears, strains, and cramps (57 vs. 36). The mechanisms associated with the observed increases in injury rate require further investigation.

Bengsston et al., (2013) also assessed the association between recovery time, injury rates and match performance in elite soccer. Exposure and time loss injuries were registered prospectively from 27 elite teams over 11 seasons. Matches were grouped in relation to the number of recovery days (≤ 3 days vs. > 3 days and ≤ 4 days vs. ≥ 6 days) before the completion of each match. Injury data was collected for all time loss injuries with injury type and severity being recorded. The authors identified that total injury rates and muscle injury rates were greater in league matches performed with ≤ 4 days when compared to ≥ 6 days recovery, with KF and KE injuries being the most greatly influenced. These data suggest that successive matches played with ≤ 4 days recovery may expose players to increased injury risk. This study supports the observations made by Dupont et al., (2010) and further reiterates the need to further assess the mechanisms associated with these increased rates of muscular injuries associated with periods of fixture congestion.

Carling et al., (2012) and Dellal et al., (2015) both assessed and compared match injuries during prolonged periods of fixture congestion (six-eight games performed over eighteen-twenty-six days) with injuries sustained during non-congested periods. Both studies identified no differences in the total injury incidence recorded in the matches completed during the congested periods when compared to those completed outside of this period. Furthermore, both studies identified that mean lay-off duration of injuries was lower

during the congested period when compared to the non-congested period. However, in support of Dupont et al., (2010), Dellal and colleagues identified an increase in the total injury rate during congested matches when compared to non-congested matches. These data suggest that prolonged periods of fixture congestion may influence injury rates and mean lay-off durations when compared to non-congested schedules. The observed reductions in mean lay-off durations during periods of fixture congestion may be a result of the type of injury sustained during these periods. These data further suggest that future research should attempt to assess the mechanisms associated with injury risk during periods of fixture congestion.

2.4.3 Summary

Previous fixture congestion literature has identified no differences in physical performance when three successive matches are performed with a minimum of 72 h interspersing each match (Carling and Dupont, 2011; Folgado et al., 2015); however, when three matches are performed over six days players have been observed to reduce the volume of activity performed in the final match (Odetoyinbo et al., 2007). The previous literature has also identified that more prolonged periods of fixture congestion do not appear to elicit changes in physical performance across the successive matches (Dellal et al., 2015), but may impair acute laboratory based measures of physical performance. Periods of fixture congestion also appear to expose players to increased risk of injury when successive matches are interspersed by less than 96 h (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015), thus suggesting an issue with mechanical and muscular recovery during periods of fixture congestion. Future research should therefore attempt to assess the physical mechanisms associated with the observed reductions in performance and increased injury risk during periods of short-term fixture congestion.

2.5 RECOVERY FROM SOCCER MATCH-PLAY

Soccer match-play stresses physiological, mechanical, biochemical, and psychological processes (Bishop et al., 2008) resulting in temporary, cumulative, and residual fatigue (Mohr et al., 2003; Krstrup et al., 2006b; Barros et al., 2007; Rampinini et al., 2009; Bradley et al., 2009; Ascensão et al., 2008; Ispirlidis et al., 2008; Andersson et al., 2008). The aforementioned stressors are particularly affected when successive bouts of training and/or match-play result in reductions recovery time. Insufficient rates of recovery have been shown to be negatively influence both performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) and injury risk (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015). Due to the perception of reduced recovery time between successive

matches, there has recently been an increase in the amount of research that has attempted to assess time course of physical recovery following the completion of soccer match-play.

2.5.1 Time course of recovery

Ascensão, et al., (2008) examined the time course of recovery associated with a number of measures (CK, MS, 20 m sprint times, and concentric KE and KF PT) following the completion of a single competitive match. The authors identified that MS and CK were not fully recovered within 72 h following the completion of a match, and that both CK and MS were significantly and moderately correlated with reductions in sprint performance. Similar to the MS and CK data, 20 m sprint performance and KE PT remained significantly impaired 72 h post-match. The similar post-trial recovery response identified with CK and MS and their relationship with impaired sprint performance suggests that MS and muscular strength/performance measures may offer a time efficient and more economical method of assessing muscle damage when compared to the assessment of CK. The KF PT data remained 10% lower than pre-match values 72 h post-match. A limitation of the work of Ascensão et al., (2008) was that although the use of actual match-play offers high ecological validity, the activity profile is not standardised for all players. It is well recognised that the fatigue response is specific to the activity performed (Drust et al., 2000b; Greig et al., 2006), as such; different players will have experienced different physical loads during the completion of the match.

Similarly, Ispirlidis et al., (2008) also assessed the time course of recovery associated with a number of physical performance measures (vertical jumps, a 20 m sprint, and a one repetition max) following the completion of a competitive soccer match. However they also monitored the time course of recovery over a more prolonged period (one week), and were therefore able to identify when measures were fully recovered. The authors identified that vertical jump performance, maximal squat strength, and 20 m sprint performance took 72, 96, and 120 h respectively to return to pre-match levels. In addition to the performance measures discussed previously, Ispirlidis et al., (2008) also identified that CK peaked at 48 h but required an extra 24 h to return to baseline (96 h). However, they also did not standardise the recovery response in relation to the physical response experienced by each player during the match.

More recently Magalhães et al., (2010) analysed the cumulative and residual fatigue response elicited from the completion of the LIST (Nicholas et al., 2000), compared to the fatigue response elicited from match-play. Measures of HR, muscle damage, redox status, blood leukocytes, and neuromuscular function were recorded at rest, and 30 min, 24 h, 48

h, and 72 h following the completion of both the LIST and a competitive match. The authors identified that measures of CK and MS increased across all post-trial measurement points, with no significant differences in the response elicited from the LIST and the match. The authors also identified that 20 m sprint performance, counter movement jump performance (CMJ), and both KE and KF concentric PT were significantly impaired until 72 h post-match. With the exception of 20 m sprint performance (significantly lower at 30 min and 24 h post LIST when compared to match), there was no significant difference in the neuromuscular fatigue response observed between the LIST and the match. These data suggest that measures of CK, MS, and neuromuscular function require more than 48 h to fully recover. These data also support the use of SSEP's to assess the cumulative and residual fatigue response associated with soccer match-play.

Rampinini et al., (2011) also attempted to assess the cumulative and residual fatigue response elicited from 20 professional soccer players following the completion of a competitive match. The authors recorded MVC's, sprint and passing ability, MS, maximal voluntary activation of KE, EMG activity of the vastus lateralis, and evoked KE contractile properties (using different electrical stimulations) before, immediately post-match, and at 24 and 48 h post-match. The authors identified that MVC, sprint performance, MS, percentage of voluntary activation of KE, vastus lateralis EMG activity, and KE contractile properties (using paired simulations at 10 Hz) were all fully recovered 48 h post-match. The authors identified that the cumulative and residual fatigue response associated with the completion of soccer match-play is determined by a combination of central and peripheral factors. Central fatigue seems to explain the observed reductions in MVC and sprinting ability, whereas peripheral fatigue seems to be more related to increases in muscle soreness due to muscular damage and associated inflammation. The measures recorded by Rampinini et al., (2011) were all recovered within 48 h following the completion of a competitive match.

2.5.2 Recovery strategies

The aforementioned studies have identified that it can take up to 120 h to fully recover following the completion of soccer match-play. As previously discussed, modern soccer teams are not afforded the luxury of 120 h interspersing each competitive match, and instead are often required to perform with only 48-72 h recovery between matches (Dupont et al., 2010; Rollo et al., 2014; Carling et al., 2015; Dellal et al., 2015). Barnett (2006) stated that for an athlete to optimally prepare for upcoming training and competition, they may have to implement strategies that artificially speed up the natural time-course of

recovery. Previous literature has assessed the effectiveness of a number of recovery strategies in (Reilly and Rigby 2002; Tessitore et al., 2007; Andersson et al., 2008; Ingram et al., 2009; Kinugasa and Kilding, 2009; Gunnarsson et al., 2011; Rowsell et al., 2011; Ascensão et al., 2011; Rey et al. 2012a; Rey et al., 2012b Valle et al., 2013), with active recovery being one of the most commonly utilised methods. A study conducted by Nédélec et al., (2013) identified that 81% of practitioners who were in charge of recovery strategies for elite French soccer teams used active recovery. Previous research has therefore attempted to assess the effectiveness of active recovery following the completion of soccer-specific activity (Reilly and Rigby 2002; Tessitore et al., 2007; Andersson et al., 2008; Kinugasa and Kilding, 2009; Rey et al. 2012a; Rey et al., 2012b).

Reilly and Rigby (2002) employed a between-subjects matched-pairs design with university soccer players to assess the influence of post-match active recovery on a number of physical performance measures (broad jumps, a sprint fatigue test, vertical jumps, and 30m sprints). An experimental group performed a 12 min active recovery session immediately post-match whereas a control group performed 12 min of passive seated recovery. The performance measures were assessed pre-match, immediately following the completion of the match, and at both 24 and 48 h post-match. The authors found that irrespective of group, the soccer match elicited reductions in all physical performance measures. Vertical jump, broad jump and 30 m sprint performance remained impaired for both groups 48 h post-trial; however, when compared to the passive recovery group, the active recovery group recovered these performance measures to a greater extent. This data suggests that immediately post-match active recovery is beneficial for the recovery of a number of performance measures. However, this study is limited by the fact that the authors did not assess the impact of the active recovery intervention on a successive bout of match play, and the performance measures which were used were acute measures of performance which are not indicative of soccer match performance. The data reported by Reilly and Rigby (2002) is also not indicative of an elite population.

Tessitore et al., (2007) attempted to assess the most effective recovery intervention to implement with elite youth soccer players during a congested training schedule. The authors utilised a number of physical performance (squat jump, CMJ, bounce jump, and 10 m sprint) and MS measures to assess the effectiveness of passive, dry-aerobic, water-aerobic, and electrostimulation recovery strategies. A repeated measures within-subject design was completed, whereby a standardised training session was performed on four separate occasions followed by the implementation of 20 min bout of each of the

aforementioned recovery strategies. All subjective and performance measures were completed prior to training and 5 h after the completion of each recovery intervention. No main effect for recovery intervention was observed for any of the performance measures; however, the dry-aerobic and electrostimulation methods were more beneficial than the other two methods for reducing the participant's perceptions of MS. These data suggest that active recovery performed after a bout of soccer-specific activity may aid the participant's perceptions of MS, thus potentially influencing the player's perceived ability to exercise again in a successive session. In contrast to the work of Reilly and Rigby (2002), Tessitore and colleagues attempted to standardise the physical load elicited from each training sessions.

Similar to the work of Tessitore et al., (2007), Kinugasa and Kilding, (2009) attempted to assess the effectiveness of different recovery strategies in youth soccer players. On separate days, 28 youth soccer players performed 3 soccer matches each randomly followed by a post-match recovery modality. The recovery modalities comprised an intermittent cold water immersion (12 °C) and hot shower (38 °C) routine, a combined cold water immersion and active recovery (cycle ergometer), and a passive post-match routine (stretching and leg raises). Perceptual (perceived total quality of recovery [TQR], thermal sensation, and leg heaviness [LH]), physiological (tympanic temperature and HR), and vertical jump height were recorded pre-match, 10 min post-match, post-recovery, and 24 h post-match. Although initially reduced post-match, jump height was recovered within 24 h. Perceptions of TQR were immediately higher following the combined recovery modality, but no difference was observed 24 h post-match. Similarly LH was lower 24 h post-match following the completion of the combined modality when compared to the other two modalities. These data therefore suggests that the combined recovery modality had a positive effect on perceptual measures following the completion of soccer match-play. It should be acknowledged that the data reported by Kinugasa and Kilding (2009) may not be reflective of an adult population.

Two studies conducted by the same research group attempted to assess the effectiveness of active (12min submaximal running and 8 min static stretching) and passive (20 min seated rest) recovery strategies on the rate of recovery associated with a number of measures following the completion of soccer-specific training (Rey et al., 2012ab). The methodologies utilised in the two studies were similar, with the only differences being the measurements that were recorded in each study. The authors randomly allocated 31 elite soccer players into two groups; one group completed the active recovery modality whilst the other completed the passive recovery modality following the completion of a

standardised training session (no significant differences in HR and ratings of perceived exertion between the two groups). In one study (Rey et al., 2012a), measures of MS and tensiomyography of selected lower limb muscles were recorded pre-training and 24 h after the completion of the respective recovery modality, whereas in the other study (Rey et al., 2012b) physical performance (CMJ, 20 m sprint, and Balsom agility test) and leg flexibility (goniometric measures performed on the KF, KE and GC) were recorded pre-training and 24 h after the completion of the respective recovery modality. In the Rey et al., (2012b) study, CMJ performance was significantly higher following the completion of the active recovery session. There were no significant differences in the measures of lower limb flexibility or in the other performance measures recorded between the two groups. Rey et al., (2012a) observed no differences in the MS and tensiomyography data recorded 24h after the completion of the two recovery modalities. The results suggest that, with the exception of CMJ performance, active recovery did not appear to elicit a beneficial effect on any of the other measures.

To the authors knowledge only one previous study (Andersson et al., 2008) has considered the influence of insufficient physical recovery on a successive bout of soccer match-play. This study also attempted to assess the effectiveness of an active recovery intervention administered during the interspersing recovery period between the two matches. A total of seventeen elite female soccer players were randomly assigned to either an active or passive recovery group. The participants were required to complete two matches which were interspersed with a 72 h recovery period. A number of measures (20 m sprint times, CMJ performance, concentric KF and KE PT, CK, urea, and uric acid) were recorded prior to and following the completion of each match. The active recovery group completed a 1h active recovery protocol (20 min of submaximal cycling at 60% HR_{peak} , 30 min of LI resistance training at < 50% of 1RM, and a further 10 mins of submaximal cycling) at 22 and 46 h after the completion of the first match.

Andersson et al., (2008) identified that there was no significant between group differences in the time course of recovery associated with any of the aforementioned measures. It was identified that 20 m sprint time, KE PT, KF PT, CK, and both urea and uric acid took 5, 21, 51, 69, and 21 h respectively to return to baseline. Counter movement jump performance remained significantly impaired at the start of the second match; however, there was no observed difference in the rate of recovery following the completion of the two matches. These data suggest that the active recovery protocol was not effective in aiding the rate of recovery associated with the neuromuscular or biochemical measures, and this may be related to the high volume of activity performed across the two active

recovery protocols. An interesting finding of the study conducted by Andersson et al., (2008) was that there was no significant difference in the amount of HI distance covered between the two matches; however, significantly higher mean HR data was recorded in the second trial. This data therefore suggests that the players elicited an increased physiological response in the second match to achieve the same level of activity. It should however be acknowledged that the current data may only be indicative of a female population, and therefore, future research should attempt to complete a similar methodology with a male cohort of players.

2.5.3 Summary

As previously discussed in this chapter, although the assessment of soccer match-play offers high ecological validity, matches are susceptible to between-subject and between-match variations (Stølen et al., 2005; Gregson et al., 2010; Rollo et al., 2014). Soccer match-play will therefore elicit different cumulative fatigue responses between players, thus influencing the residual fatigue response experienced post-match. It is therefore difficult to interpret the residual fatigue response elicited by the studies reviewed previously in this section. Valid SSEP's may therefore offer a unique opportunity to standardise the cumulative fatigue response experienced by each player, thus allowing for a better interpretation of the post-match residual fatigue response.

With the exception of the study conducted by Andersson et al., (2008), previous literature has focussed on assessing the time course of recovery following the completion of a soccer match without considering the influence of insufficient recovery on a successive bout of match-play. Future research may therefore utilise valid SSEP's to assess the influence of insufficient recovery on a successive bout of soccer-specific activity.

It has previously been identified that the rate of post-exercise recovery is specific to the physical load imposed by the preceding exercise bout (Nédélec et al., 2012). Recovery strategies should therefore be specific to the physical fatigue response elicited from the bout of exercise. Developing a better understanding of the mechanisms associated with cumulative and residual fatigue associated with the completion of soccer-specific activity is therefore critical for the design of effective recovery strategies (Minet and Duffield, 2014). It is evident from the previous literature that active recovery protocols may be useful in aiding the rate of post-match recovery; however future research is warranted to further assess this. Furthermore, an amalgamation of recovery strategies seems to be most beneficial in artificially aiding the rate of post-match recovery.

2.6 SYNOPSIS OF LITERATURE

Research has previously investigated the physical demands and physical response associated with the completion of soccer-specific activity. Although soccer match-play offers high ecological validity, matches are susceptible to high between-match and between-player variations. Similarly, due to both the nature of soccer, and the rules imposed by governing bodies, the assessment of physical measures during match-play is often impractical or prohibited. A large number of research groups have therefore previously attempted to replicate the physical demands and response to match-play by developing SSEP's. However, common to most attempts at developing valid SSEP's are validation issues. There therefore exists the need for the development of a novel SSEP that is representative of the activity profile of contemporary soccer match-play, and which elicits a valid physical (biomechanical and physiological) response.

Modern soccer-match play has been shown to have evolved to now be characterised by an increased number of HI efforts performed across a match, and an increased frequency of matches performed across a season. These observed evolutions in demands of modern soccer may explain the high prevalence of KF strain injuries associated with modern soccer players. Although, the physiological response to match-play may contribute to the observed temporary and cumulative reductions in performance, the physiological response does not appear to cause the increased injury risk observed towards the latter stages of each half. The mechanical and muscular response to soccer-specific activity should therefore be afforded increased attention.

As previously suggested, fixture congestion poses a contemporary issue in soccer, with potential implications for increased injury risk and reductions in performance due to a reduction in recovery time between successive matches. The development of a novel and contemporary SSEP may therefore be utilised to mechanistically assess the physical response associated with simulated periods of short-term fixture congestion, thus informing the development of innovative strategies to reduce the residual fatigue response associated with successive bouts of soccer-specific activity.

2.7 RESEARCH HYPOTHESES

The specific hypotheses associated with the current thesis are:

- 1) The development of a contemporary SSEP will offer a valid simulation of the physical response and velocity profile associated with soccer match-play
- 2) There will be a difference in the residual fatigue response associated with the completion of two SSEPs interspersed with either a 48 or 72 hour recovery period.
- 3) There will be a residual physical fatigue response associated with the completion of three SSEPs each interspersed with 48 hours recovery.
- 4) The temporary, cumulative, and residual physical fatigue response associated with the completion of successive bouts of different exercise modalities will be specific to each modality.
- 5) The implementation of a contemporary rule change intervention will have a positive effect on the temporary, cumulative, and residual fatigue response associated with the completion of soccer-specific activity.
- 6) The development of a novel recovery intervention will have a positive effect on the residual fatigue response and injury risk associated with periods of soccer-specific fixture congestion.

CHAPTER THREE

GENERAL METHODS

3.1 IDENTIFICATION OF RESEARCH PARTICIPANTS

Semi-professional male soccer players volunteered for each study. Participant's eligibility was determined using stringent inclusion and exclusion criteria. The inclusion criteria specified that players demonstrated the capacity to complete a 30 min familiarisation sessions specific to the SSEP, were outfield players, were injury free for a minimum of 6 months prior to testing, and had no previous history of KF injuries. It has been identified that athletes with previous KF injury elicit altered BF muscle activity and altered running kinematics (Daly et al., *In Press*). Additional to weekly matches, the participants were also required to have completed typical training volumes equating to $> 4 \text{ h}\cdot\text{wk}^{-1}$ of soccer-specific conditioning drills during the preceding soccer season. Participants were excluded from the studies if they were allergic to tape used within the studies, possessed history of cardiovascular or pulmonary disease, or had smoked during the preceding 12 months prior to the start of a study.

3.2 ETHICAL CONSIDERATIONS

Participants were informed of the risks and procedures involved in testing and were required to provide written informed consent prior to the commencement of any of the studies. The experimental protocol was previously approved by the local university ethics committee and conformed to the Declaration of Helsinki. All equipment was risk assessed and calibrated in accordance to the manufacturers guidelines prior to testing commencing.

3.3 PRE-EXERCISE MEASUREMENTS

Prior to start of each experimental trial, participants were required to undergo a comprehensive health screening procedure to further assess the participant's eligibility and also highlight potential risks. Both heart rate and blood pressure were measured (Omron, Mx3 plus, Netherlands), values of $> 90 \text{ b}\cdot\text{min}^{-1}$ and $> 140 \text{ mmHg}/90 \text{ mmHg}$ respectively were contraindications to exercise. Prior to the start of the each study, the participants age (yrs), height (cm) and mass (kg) were measured and recorded using a wall-mounted stadiometer (Holtain, Harpenden HSK-BI, UK) and top pan scales (Seca, Germany) respectively.

3.4 EXPERIMENTAL DESIGN AND CONTROLS

In an attempt to control for circadian variation (Kline et al., 2007), all experimental trials were completed between 1700 and 2000 h in accordance with the participants regular

training times (Rae, et al., 2015). All trials were conducted in an ambient controlled environmental chamber with temperature and humidity maintained at 21 ± 0.5 °C and 35 ± 1.5 % respectively. For all studies, participants were required to consume a minimum of 500 ml of water 2 h prior to testing, refrain from consuming caffeine 24 h prior to all experimental trials, and attend the laboratory on each occasion in a 3 h post-absorptive state following a 48 h period of abstinence from vigorous exercise, the use of recovery strategies, and alcohol. For studies 2-5, participants were also asked to wear similar apparel and the same running shoes for each trial. Furthermore, participants were also asked to consume similar meals between successive trials. Prior to each experimental trial, a portable refractometer (Osmocheck, Vitech Scientific, West Sussex, UK) was used to ensure participants were euhydrated (urine osmolality of <700 mOsm/kgH₂O). Where the equipment and exercise protocol permitted, the participants were allowed to consume water ad libitum; however, no alternative drinks or foods were allowed to be consumed during any of the experimental trials. During the completion of the experimental trials, only one male researcher and the participant were present. Previous research has identified that performance, perceptions of effort, and physiological response may be influenced by both the gender (Winchester et al., 2008) and the number (Rhea et al., 2003) of observers. To prevent the potentially performance enhancing effect of verbal encouragement and visual feedback (Andreacci et al., 2002), no visual feedback or verbal encouragement was provided during the completion of the trials.

3.5 MOTORISED TREADMILL

All trials were completed using a programmable motorised treadmill (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports and Medical GmbH, Germany) with a speed range of 0.0–11.1 m·s⁻¹ and gradient range of 0-25%. The associated manufacturer's software (H/P/Cosmos Para Graphics, H/P/Cosmos Sports and Medical GmbH, Germany) was installed onto a personalised computer and was used to control the treadmill during each trial. The dimensions of the running surface were 1.90 m long and 0.65 m wide. The velocity and gradient of the motorised treadmill was controlled by a computerised control and the velocity remained within 0.01 m·s⁻¹ of the desired velocity. The motorised treadmill was housed within an environmental chamber (Figure 3.1). Following the completion of a treadmill familiarisation trial, the participants were not required to wear the treadmill safety harness. Pilot testing identified that the use of the safety harness reduced PL_{total} values by ~10%. Similarly, previous literature has also identified that the use of a safety harness reduces running performance (time to exhaustion) by ~12% (Mermier et al., 2013).



Figure 3.1 Position of the treadmill within the environmental chamber

3.6 WARM-UP PROTOCOL

Prior to the commencement of all experimental trials participants were required to complete a standardised treadmill-based intermittent warm-up followed by a period of self-directed stretching. As depicted in figure 3.2, the treadmill-based warm-up was designed to replicate the velocities, durations, and frequency of speed changes associated with a pre-match warm up routine (Greig et al., 2006). The warm up protocol was completed prior to the completion of any muscular strength measures, was completed for a total duration of 8 mins to allow participants to become re-familiarised with treadmill-based running, and was completed 20 mins prior to the commencement of any experimental trial. The inclusion of a 20 min down time following the completion of the warm up was provided to achieve an ergogenic effect. Prior to the first familiarisation trial, the participants were familiarised with both a standardised stretching technique and also the velocity profile associated with the treadmill-based warm up. On all subsequent occasions the participants were required to react to the speed changes in an attempt to increase the physical response, whilst also ensuring the participants were familiarised with the intermittent nature of the experimental trials.

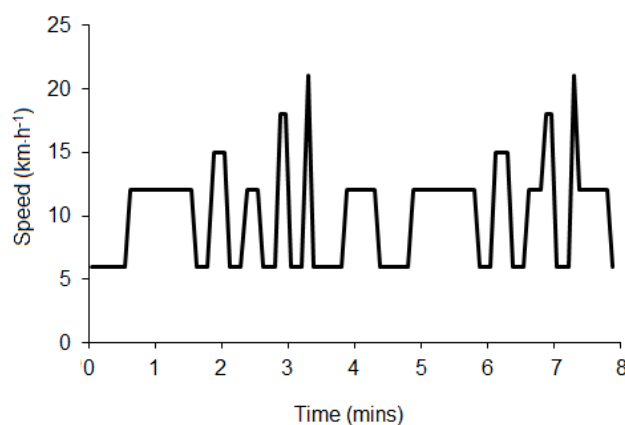


Figure 3.2 Schematic of the treadmill-based warm-up (Greig et al., 2006)

3.7 PHYSICAL MEASURES

3.7.1 *Blood lactate*

For studies 1 (Chapter 4), 2 (Chapter 5), and 3 (Chapter 6), BLa concentrations were measured at pre-determined measurement points via a capillary finger-tip blood sample. The fingertip was initially prepared using an alcoholic swab to sterilise the area before a sterile disposable automated lancet device (AccuCheck Safe-T-Pro, Indianapolis, USA) was used to create a small incision on the fingertip. As instructed by the manufacturer, a free-flowing capillary blood sample was then analysed using a portable lactate analyser (Lactate Pro two, LT-1730, Akray Factory Inc, KDK Corporation, Kyoto, Japan). The lactate pro analyser has been identified as a reliable measure ($r = 0.99$) of whole blood lactate concentrations (Pyne et al., 2000) and has been shown to be more accurate and reliable when compared to other portable lactate analysers (Tanner et al., 2010).

3.7.2 *Cardiorespiratory measurements*

For studies 1 (Chapter 4), 2 (Chapter 5), and 3 (Chapter 6), breath by breath expired air was telemetrically recorded at rest (following a 20 min period of supine rest) and continuously throughout each trial using a portable metabolic gas analyser (Cosmed K4b², Cosmed, Rome, Italy). Prior to start of data collection the Cosmed device was initially warmed up for a minimum period of 30 mins, before both the turbine and the gas analysers were calibrated (in accordance with manufacturer's instructions). Prior to the start of each experimental trial, the participants were fitted with a rubberised facemask (secured in place via an adjustable headpiece), and an adjustable anatomical harness to house the portable unit. To reduce any impairment on running technique, the metabolic analyser and battery pack were secured to thoracic region of the participant's back. To allow for the collection of data, a bi-directional digital turbine and sampling plug were attached to both the facemask and the portable unit. The digital turbine and sampling plug measure the airflow rate and concentrations of both expired oxygen and carbon dioxide respectively. Prior to the commencement of data collection the relative humidity, environmental temperature, and the size of the facemask were manually entered into the Cosmed K4b² software (installed onto a personal computer). The Cosmed software is then used to telemetrically receive the breath by breath data measured by the portable unit. Following the completion of each trial, the data files were downloaded to an Excel file, and values for mean ($\dot{V}O_2$) and peak oxygen consumption ($\dot{V}O_{2peak}$) were calculated for pre-determined periods of activity. Absolute oxygen consumption data was normalised using pre-exercise body mass. Body mass was recorded pre-exercise using an electronic load cell scale (Bodpod version

4.2.0, Life Measurement Inc, USA). The Cosmed K4 b² system has been shown to possess good test-retest reliability with interclass correlation coefficients (ICC's) of 0.7-0.9 for values of $\dot{V}E$, $\dot{V}O_2$, and $\dot{V}CO_2$ (Duffield et al., 2004).

During studies 2 (Chapter 5) and 3 (Chapter 6), average (HR) and peak heart rates (HR_{peak}) were recorded using a heart rate monitor (Polar Team System, Polar Electro, Kempele, Finland) synchronised with the metabolic analyser. For studies 4 (Chapter 7) and 5 (Chapter 8) HR and HR_{peak} were recorded using a heart rate monitor (Polar Team System, Polar Electro, Kempele, Finland) synchronised with the GPS unit. For studies 2-5, values for HR and HR_{peak} were quantified at rest (following a 20min period of supine rest) and for pre-determined periods of activity.

3.7.3 Accelerometry

For all studies, GPS-based (MinimaxX, S4, Catapult Innovations, Scoresby, Australia) accelerometry (Kionix KX94, Kionix, Ithaca, New York, USA) was recorded at 100 Hz to quantify tri-axial PlayerLoadTM (PL_{total}). Tri-axial PlayerLoadTM is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three movement planes (Boyd et al., 2011). To reduce movement artefact the GPS device was housed in a standardised neoprene vest (Catapult Innovations, Scoresby, Australia) at the cervical region of the spine. It has recently been suggested that the GPS device may be better housed at the lumbar region of the spinal column, due to the cervical position potentially underestimating the PlayerLoadTM response to exercise (Barrett et al., 2014). Nevertheless, the literature associated with the manipulation of GPS device location is limited, and as such, the decision was made to house the unit in the manufacturer's suggested location. The PlayerLoadTM data was recorded for the duration of each experimental trial, and was retrieved post-testing using the Catapult Sprint software (Version 5.0.9.2; Firmware 6.75). Uni-axial PlayerLoadTM was also quantified in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}) and vertical (PL_V) movement planes for pre-determined periods of activity. The relative contributions of each uni-axial PlayerLoadTM vector to PL_{total} ($PL_{ML}\%$, $PL_{AP}\%$, and $PL_V\%$) were also quantified. Barrett et al., (2014) identified that the test-retest reliability of the PlayerLoadTM metric during the completion of an incremental treadmill-based running protocol was moderate to high (ICC 0.80-0.93).

3.7.4 Perceptions of muscle soreness

For studies 3 (Chapter 6), 4 (Chapter 7), and 5 (Chapter 8), participants were required to provide their perceptions of lower limb MS at pre-determined periods using a visual

analogue scale (VAS). The VAS scale consisted of a 10-cm continuous line with “not sore at all” on the left end of the line (0 cm) and “very, very sore” on the right end of the line (10 cm) (Chen and Nosaka 2006). For studies 3 (Chapter 6) and 4 (Chapter 7), participants were instructed to stand with knees shoulder-width apart and squat slowly to a position of $\sim 90^\circ$ of knee flexion, before marking their perceived level of MS onto the continuum. For study 5 (Chapter 8), participants were required to perform a single leg squat with each leg to a knee joint angle of $\sim 65^\circ$, before marking their perceived level of MS for each leg onto the continuum. A new VAS was used for each measurement to avoid bias from the previous measurement. A score of 0-100 was quantified by measuring the distance to the nearest 0.1cm from the left end of the line to the participants perceived level of soreness. Rampinini et al., (2011) identified ICC's of 0.65 for the aforementioned method.

3.7.5 Isokinetic dynamometry

For study 3 (Chapter 6), eccentric KF PT was quantified using an isokinetic dynamometer (IKD) at speeds of 300 and 60 $\text{deg}\cdot\text{s}^{-1}$ (5.25 and 1.05 $\text{rad}\cdot\text{s}^{-1}$). For studies 4 (Chapter 7), and 5 (Chapter 8), eccentric KF PT, APT, and the functional range at 80% of PT (FR_{80}) was quantified using an isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, New York, USA) at speeds of 180, 300 and 60 $\text{deg}\cdot\text{s}^{-1}$ (3.14, 5.25 and 1.05 $\text{rad}\cdot\text{s}^{-1}$). The testing speeds were chosen to replicate speeds previously utilised in soccer-specific literature (Greig 2008), whilst also providing an indication of the force-velocity profile of the dominant limb KF musculature. The order of the speeds was chosen to reduce the potential fatigue effect induced by the slower isokinetic speed (Greig 2008). For each speed, participants were instructed to perform 5 (dominant leg) maximal contractions through their full range of movement. Passive concentric knee flexion at 60 $\text{deg}\cdot\text{s}^{-1}$ separated each repetition, and a rest period of 30s interspersed each set. No performance feedback was provided during any of the experimental trials. The dynamometer setup was adjusted specifically for each participant in line with the manufacturer's guidelines, with the cuff of the lever arm secured around the ankle proximal to the malleoli. Restraints were applied proximal to the knee joint across the thigh, across the waist, and across the participant's chest. The lever arm was aligned with the axis of rotation of the knee joint and the anatomical reference was set at 90° . Prior to the commencement of data collection, the passive flexion of the participant's leg was recorded to correct for the effects of gravity. The isokinetic phase (disregarding torque overshoot) of each repetition was analysed, with the repetition with the highest PT being chosen for further analysis. A cut-off of 1% was used to identify the isokinetic phase of the movement. Greig (2008) identified ICC's of 0.78, 0.78, and 0.76 for eccentric knee flexion recorded at 60, 180 and 300 $\text{deg}\cdot\text{s}^{-1}$.

3.7.6 Electromyography

For studies 3 (Chapter 6), 4 (Chapter 7), and 5 (Chapter 8), EMG data was recorded from the dominant (defined as preferred kicking leg) BF muscle. Following careful skin preparation including removal of excess hair and cleaning with an isopryl swab, pairs of disposable bipolar silver-silver chloride (Ag/AgCl) passive wet gel surface electrodes (inter-electrode distance 2cm) (Noraxon USA inc, Arizona, USA) were applied to the muscle. Electrode placement was in accordance with previous recommendations (Hermens et al., 2000). Electrodes were applied parallel to the muscle fibre alignment, and were positioned over the mid-belly of the muscles, between the myotendinous junction and the site of innervation. Small telemetric modules were connected to the electrodes via a two snap lead and were secured to the participant's skin using double sided adhesive tape. The telemetric modules possessed a built in reference electrode which remained in contact with the participants skin during the completion of the trials. The electrodes and telemetric receivers were firmly taped to the participant's leg to ensure they remained in place during the completion of the trials. To further ensure that the electrodes and telemetric modules remained in place for the duration of each trial, athletic under wrap was also applied to the participant's thigh. The telemetric modules transmitted the EMG signals to a receiver (Noraxon Telemetry DTS System, Noraxon USA inc, Arizona, USA) attached to a personal computer. To ensure optimal transfer of the EMG signal via Wi-Fi, the EMG system initially high pass filters the data at 10 Hz and then low pass filters at 500 Hz. The recorded EMG signals were analysed using the manufacturer's software (MyoResearch 3.4, Noraxon, USA). Initially, the raw EMG data was filtered to remove movement artefact using a high pass filter of 40 Hz, and was then smoothed using a RMS smoothing factor of a 50 ms time constant. Specific details with regards to the EMG measurement parameters will be provided in each study. Electrode positioning was marked on the skin in order to ensure repeatability of marker placement. Participants were asked to reapply the mark during the interspersing recovery periods to ensure that it remained visible.

CHAPTER FOUR

STUDY ONE

THE BIOMECHANICAL AND PHYSIOLOGICAL RESPONSE TO A CONTEMPORARY MATCH-PLAY SIMULATION

Parts of this chapter have been published in:

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4.1 INTRODUCTION

The influence of fatigue on both performance and injury risk in soccer has been well documented, driving the development of SSEP's designed to replicate the physical demands of match-play (Abt et al., 1998; Bishop, et al., 1999; Drust et al., 2000ab; Nicholas et al., 2000; Greig et al., 2006; Small et al., 2009; Williams et al., 2010; Russell et al., 2011; Bendiksen et al., 2012; Clarke et al. 2012; Aldous et al., 2014). Typically authors refer to the activity profile as validated against notational analyses of match-play. Soccer is characterised by an intermittent and irregular activity profile, increasing the complexity of both the biomechanical and physiological response. Recently, PlayerLoad™ calculated from the tri-axial accelerometer function of GPS devices has been used as a biomechanical measure of intensity in intermittent team sports (Boyd et al., 2011; Cormack et al., 2013; Scott et al., 2013; Barron et al., 2014; Cormack et al., 2014; Walker et al., 2015). Technological advancements have enhanced the collection of data during match-play, which offers the ultimate in ecologic validity, but a lack of experimental control. Laboratory protocols offer the control required to mechanistically examine the influence of stressors relevant to the elite soccer players. Practical applications could include the investigation of fixture congestion and recovery strategies, heat stress, return-to-play assessments, and the manipulation of running velocity profiles for training purposes (overload or rehabilitation). Laboratory protocols also provide a reduced injury risk, negating the physical contact which accounts for more than 70% of all injuries (Aoki et al., 2012).

Where SSEP's have utilised prolonged bouts of HI work (Bishop et al., 1999; Drust, Reilly, and Cable. 2000; Nicholas et al., 2000; Williams et al., 2010; Russell et al., 2011) to elicit a favourable physiological response, they have invalidated the biomechanical integrity of the velocity profile. However, a high frequency of speed changes to more accurately model the velocity profile has elicited a low physiological response (Greig et al. 2006). The structure of the intermittent velocity profile will inevitably affect the physical response, and the arbitrary and ad hoc distribution of speed changes used in previous studies may not reflect match-play. Contemporary notational analyses suggest that HI efforts in team sports typically occur in 'clusters' (Spencer et al. 2004). By clustering the HI efforts incidences of instantaneous fatigue (Bangsbo et al., 2007; Impellizzeri et al., 2008, Mohr et al., 2003; Rampinini et al., 2009) can be induced and an elevated and valid physical response can be achieved. The aim of this study was to design a novel treadmill based SSEP characterised by clusters of HI efforts, and validate both the velocity profile and the physical response in relation to previous soccer-specific literature. A secondary

aim is to consider the previous criticism of treadmill-based SSEP's as being uni-directional, and thus not replicating the mechanical load associated with match-play (Small et al., 2009).

4.2 METHOD

4.2.1 Participants

Eighteen male semi-professional soccer players (mean \pm SD: age 22.5 ± 3.5 yrs, height 177.4 ± 6.8 cm, body mass 76.5 ± 6.8 kg), volunteered to complete this study within a month, after the end of the competitive soccer season. Due to the novel nature of the current SSEP, a sample size calculation was not performed *a priori*. The current sample size was therefore informed from previous literature associated with the development of treadmill-based SSEPs (Drust et al., 2000ab; Greig et al., 2006; Small et al., 2009). Participant's eligibility was determined from the inclusion and exclusion criteria described in Chapter 3.1. Preliminary anthropometric and health screening procedures were also completed as described in Chapter 3.3. The current study conformed to all ethical considerations described previously in Chapter 3.2.

4.2.2 Experimental design

Participants attended the laboratory on three occasions to complete two familiarisation trial followed by an experimental trial. A minimum of 72 h recovery interspersed each of the three trials. The experimental design and controls are described in more detail in chapter 3.4. All trials were completed on a programmable motorised treadmill (Chapter 3.5). The familiarisation trials comprised 2 x 15 min bouts of the SSEP completed under test conditions. Prior to each trial, participants were required to complete a standardised warm-up (Chapter 3.6).

4.2.3 Experimental procedures

The experimental trial comprised of the completion of a novel treadmill-based SSEP. Figure 4.1 provides a schematic representation of the velocity profile associated with a 15 min bout of the protocol. The velocity profile was based on notational analysis of elite match-play (Mohr et al., 2003) with backward running integrated with low intensity running at a velocity of $11.6 \text{ km}\cdot\text{h}^{-1}$, and the sprint assigned a velocity of $25 \text{ km}\cdot\text{h}^{-1}$. The 90min notational data was divided to provide a 15 min bout, from which the SSEP was designed. The SSEP also incorporated varying levels of gradient to help account for the lack of air resistance associated with laboratory testing (Jones and Doust., 1996). Table 4.1 depicts the frequency, duration and treadmill inclination of each locomotion category

during a 15 min bout of the SSEP. The SSEP comprised 6 x 15min bouts of intermittent activity, with a 15 min passive recovery period interspersing the 3rd and 4th bouts to simulate HT. The maximum treadmill acceleration (and deceleration) of 1.39 m·s⁻² was applied to each change in velocity, with the duration of speed change factored into the duration of the subsequent activity. The structure of the 15 min activity period was developed to replicate the clustering of HI efforts interspersed with LI bouts as observed in match-play (Spencer et al., 2004).

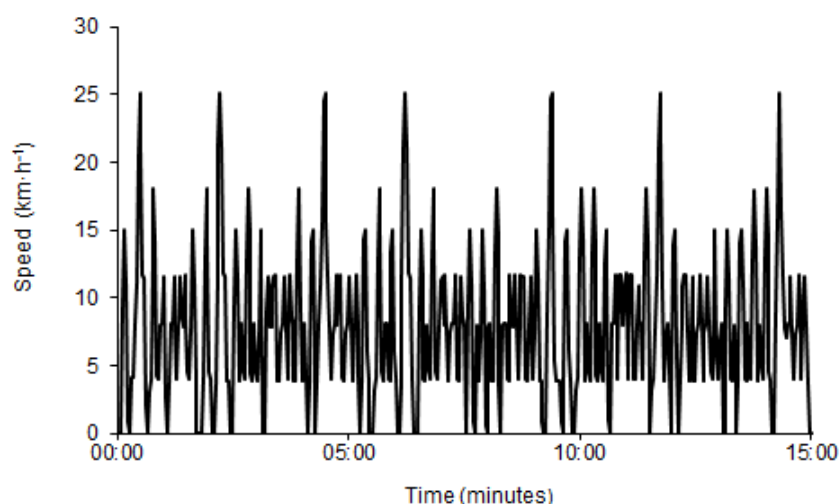


Figure 4.1 Schematic representation of a 15 min bout of the SSEP

Table 4.1 The frequency, duration and treadmill inclination of each locomotion category associated with each 15 min bout of the SSEP.

Locomotion Category (velocity)	n	Duration (s)	Gradient (%)
Standing (0 km·h ⁻¹)	29	7.0	1.0
Walking (4 km·h ⁻¹)	65	6.4	1.0
Jogging (8 km·h ⁻¹)	53	3.0	1.0
Low Speed running (11.6 km·h ⁻¹)	48	2.6	1.0
Moderate speed running (15 km·h ⁻¹)	17	2.2	2.0
High Speed Running (18 km·h ⁻¹)	12	2.1	2.0
Sprint (25 km·h ⁻¹)	7	2.0	2.5

4.2.4 Experimental measures

Further detail regarding each data collection parameter is provided in chapter 3. The physical measures were chosen to replicate those commonly used to monitor fatigue and training load within an applied sport setting (Halsen, 2014). Heart rate (Polar Team System, Polar Electro, Kempele, Finland) was recorded as point reading at rest, immediately following each 15 min bout of the SSEP, and following the passive HT

period. Blood lactate concentrations were also recorded alongside the HR measurements (Chapter 3.7.1). Average values for $\dot{V}O_2$ and $\dot{V}O_{2peak}$ were calculated at rest and for each 15 min bout of the SSEP (Chapter 3.7.2). Borg's 6-20 point scale (1970) was also used to record the participant's subjective RPE as a point reading following each 15 min bout of the SSEP. Average values for PL_{total} , PL_{ML} , PL_{AP} , PL_V , $PL_{ML\%}$, $PL_{AP\%}$, and $PL_{V\%}$ were also calculated for each 15min bout of the SSEP (Chapter 3.7.3).

4.2.5 Statistical analysis

Statistical analyses and the variables that were to be included were decided *a priori*. The assumptions associated with a repeated measures general linear model (GLM) were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardised and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. The aforementioned physical measures did not violate any of the assumptions, and therefore inferential analyses were performed using GLMs to examine differences in the physical response elicited from the completion of the experimental trial. Where significant main effects for time were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, 95% Confidence Intervals (95% CI) for difference were also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (≥ 0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean \pm SD unless otherwise stated.

4.3 RESULTS

4.3.1 Mechanical responses

Figure 4.2 illustrates the time history of changes in PL_{total} across the 90min protocol, with the GLM identifying a significant main effect for exercise duration ($P = 0.02$, $\eta^2 = 0.20$). Tri-axial PlayerLoadTM tended to increase throughout the protocol, with significantly higher values recorded at 45-60 mins ($T_{45-60} = 214.51 \pm 14.97$ a.u) when compared to the first 30 mins ($T_{0-15} = 206.26 \pm 14.37$ a.u; $T_{15-30} = 206.57 \pm 13.68$ a.u). The 95 % CI for these differences were 0.18 to 16.49 a.u and 0.07 to 15.81 a.u, respectively. Tri-axial PlayerLoadTM remained elevated throughout the second half.

A similar pattern was evident for both the PL_{AP} and PL_{ML} . Anterior-posterior PlayerLoadTM was significantly lower ($P < 0.001$, $\eta^2 = 0.38$) in the first 30 mins ($T_{0-15} = 54.74 \pm 7.66$ a.u; $T_{15-30} = 56.58 \pm 8.28$ a.u) when compared to the final 30 mins ($T_{60-75} = 61.33 \pm 9.48$ a.u; $T_{75-90} = 62.02 \pm 10.48$ a.u). The 95% CI for the differences between the first 15mins with the final 30 mins were -11.70 to -1.15 a.u and -13.93 to -0.621, respectively. The 95% CI for the differences between the second 15 mins with the final 30mins were -8.94 to -0.55 a.u and -10.78 to -0.98 a.u, respectively. Medial-lateral PlayerLoadTM was also significantly lower ($P = 0.03$, $\eta^2 = 0.17$) in the first 30 mins ($T_{0-15} = 47.14 \pm 5.48$ a.u; $T_{15-30} = 47.14 \pm 5.48$ a.u) when compared to the first 15 min bout in the second half ($T_{45-60} = 49.31 \pm 6.12$ a.u). The 95 % CI for these differences was -3.75 to -0.59 a.u and -3.82 to -0.16 to a.u, respectively. There was no significant main effect for time associated with PL_V data, with average values consistent at 104.54 ± 9.96 a.u.

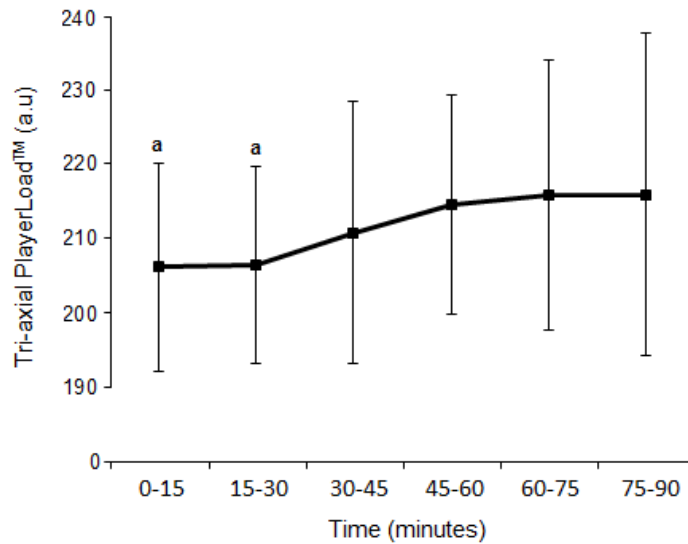


Figure 4.2 Time history of changes in total PlayerLoadTM across the 90min SSEP protocol. ^a denotes significant difference from 45-60mins.

Figure 4.3 quantifies the relative contribution of each uni-axial PlayerLoadTM vector. There was a significant increase in $PL_{AP}\%$ as a main effect for time ($P < 0.001$, $\eta^2 = 0.33$), and a compensatory decrease in the $PL_V\%$ ($P < 0.001$, $\eta^2 = 0.44$). Post hoc pairwise comparisons revealed a significantly higher $PL_{AP}\%$ values over the final 30 mins ($T_{60-75} = 28.41 \pm 3.53$ %; $T_{75-90} = 28.62 \pm 3.28$ %) when compared to the first 15 mins ($T_{0-15} = 26.60 \pm 3.67$ %). The 95% CI for these differences were 0.21 to 3.41 % and 0.37 to 3.68 %, respectively. Conversely, the values for $PL_V\%$ in the first 15 mins ($T_{0-15} = 49.27 \pm 7.30$ %) were significantly higher than the last 15 min period ($T_{75-90} = 47.30 \pm 6.66$ %). The 95 % CI

for this difference was 0.64 to 3.29 %. The repeated measures GLM did not identify a significant ($P= 0.84$) main effect for time associated with the $PL_{ML}\%$ data, with average values consistent at 22.88 ± 1.85 %.

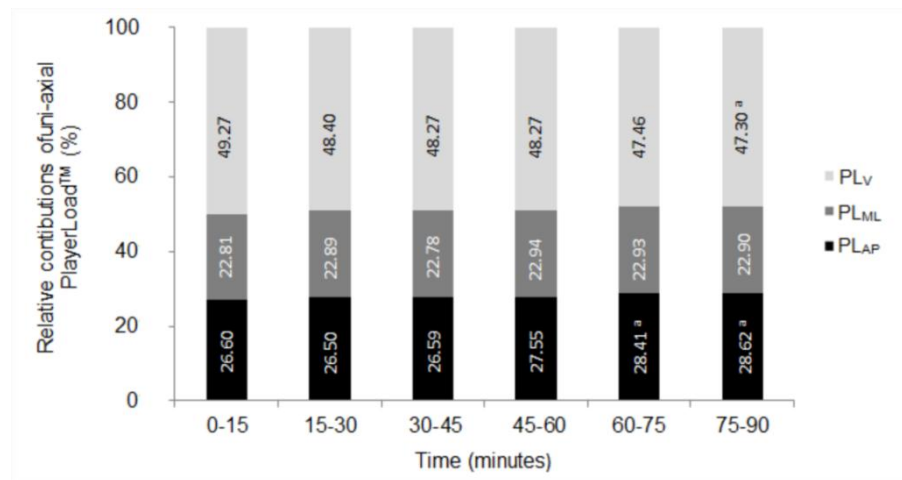


Figure 4.3 Time history of changes in the relative contributions of uni-axial PlayerLoad™ vectors with superimposed mean \pm SD data. ^a denotes significant difference from 0-15 mins.

4.3.2 RPE and physiological responses

As depicted in Table 4.2, the GLM identified a significant ($P < 0.001$) main effect for time for the HR ($\eta^2 = 0.97$), BLa ($\eta^2 = 0.26$), $\dot{V}O_2$ ($\eta^2 = 0.97$), and $\dot{V}O_{2peak}$ data ($\eta^2 = 0.95$). The GLM also identified a significant ($P < 0.001$, $\eta^2 = 0.84$) main effect for time for the RPE data, with significantly lower values recorded at Rest ($T_{rest} = 6 \pm 0$) and during the first 30 mins ($T_{0-15} = 10 \pm 2$ a.u; $T_{15-30} = 11 \pm 2$ a.u) when compared to the final 30 mins ($T_{60-75} = 13 \pm 0$ a.u; $T_{75-90} = 14 \pm 2$ a.u).

Table 4.2 Temporal physiological fatigue response associated with the SSEP.

Time (mins)	BLa (mmol·L ⁻¹)	HR (b·min ⁻¹)	$\dot{V}O_2$ (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2Peak}$ (ml·kg ⁻¹ ·min ⁻¹)
Rest	1.13 \pm 0.33	63 \pm 5 ^c	6.75 \pm 1.47	11.57 \pm 1.29
0-15	2.43 \pm 1.21 ^{ab}	162 \pm 14 ^{abd}	33.80 \pm 3.29 ^a	52.94 \pm 7.34 ^a
15-30	2.28 \pm 1.06 ^{ab}	166 \pm 14 ^{abd}	33.39 \pm 4.18 ^a	50.83 \pm 8.20 ^a
30-45	2.57 \pm 1.28 ^{ab}	165 \pm 18 ^{ab}	33.83 \pm 4.47 ^a	52.44 \pm 7.19 ^a
HT	1.47 \pm 0.55	92 \pm 16		
45-60	2.39 \pm 1.45 ^{ab}	165 \pm 15 ^{abd}	33.42 \pm 3.99 ^a	52.22 \pm 9.76 ^a
60-75	2.57 \pm 1.29 ^{ab}	168 \pm 14 ^{abd}	33.46 \pm 4.59 ^a	52.14 \pm 10.91 ^a
75-90	3.21 \pm 2.14 ^{ab}	172 \pm 15 ^{ab}	33.65 \pm 4.66 ^a	52.98 \pm 8.65 ^a

^a denotes a significant difference from rest; ^b denotes a significant difference from HT; ^c denotes a significant difference from 60-75mins; ^d denotes a significant difference from 75-90mins

4.4 DISCUSSION

The aim of the present study was to quantify and validate the physical response to a SSEP characterised by clusters of HI exercise, validated against previous notational analyses (Mohr et al., 2003; Spencer et al., 2004). The findings of this study identify that the SSEP provides a valid simulation of the TD covered, the velocity profile, and the physical response associated with soccer match-play. The current protocol, therefore, offers an opportunity of simulating soccer match-play within a safe and controlled environment. The practical applications of a valid and standardized protocol are that it can be used to assess the effectiveness of soccer-specific interventions, assess the impact of exercise stressors on performance, and can be used as a training tool or method of assessment for a player's return-to-play capabilities.

The TD covered of ~12.16 km (Saltin, 1973; Withers, et al., 1982; Ekblom, 1986; Van Gool et al., 1988 Bangsbo et al., 1991; Bangsbo et al., 1994 Mohr, et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007a; Bradley et al., 2009; Osgnach et al., 2010; Randers et al., 2010; Barnes et al., 2014), and the 8:1 ratio in LI ($<15 \text{ km}\cdot\text{h}^{-1}$) to HI work duration are similar to observations of match-play (Reilly, 1997). The frequency, duration and speed of discrete locomotive phases was based upon match-play data (Mohr et al., 2003), with the clustering of HI efforts designed to replicate match-play observations (Spencer et al., 2004). The exercise protocol thereby provides a valid representation of the distance and velocity profile associated with match-play.

Heart rate values recorded during the protocol increased from $162 \pm 14 \text{ b}\cdot\text{min}^{-1}$ following the first 15min bout to $172 \pm 15 \text{ b}\cdot\text{min}^{-1}$ at the end of the final 15min bout. Average HR values of ~157-176 $\text{b}\cdot\text{min}^{-1}$ have been recorded during semi-professional and elite match-play (Mohr et al., 2003; Mohr et al., 2012; Barrett et al., 2013). The heart rate values identified from the current protocol are similar to Drust et al., (2000b), Nicolas et al., (2000), and Barrett et al., (2013) and greater than those elicited from other SSEP's (Greig et al., 2006).

Average oxygen consumption values of $\sim 34 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $\dot{V}\text{O}_{2\text{peak}}$ values of $\sim 52 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ were recorded during the SSEP, with no significant change across the within-trial measures. Average oxygen consumption values between 37 and 56 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ have been reported in the literature (Stølen et al., 2005), these values are similar to those identified for this current study. Additional comparisons are difficult given the inherent problem of measuring $\dot{V}\text{O}_2$ during match-play.

Blood Lactate values peaked at $3.2 \pm 2.1 \text{ mmol}\cdot\text{L}^{-1}$ at the end of the protocol. The values recorded are toward the lower end of the 2-10 $\text{mmol}\cdot\text{L}^{-1}$ range reported in previous match-play literature (Bangsbo et al., 2007), but similar to those reported at the end of friendly matches (Krustrup et al., 2006b; Ispirlidis et al., 2008) and higher than attained during other treadmill protocols (Greig et al., 2006). Similar to heart rate, blood lactate concentrations recovered to near baseline levels ($1.5 \pm 0.6 \text{ mmol}\cdot\text{L}^{-1}$) following the HT period. It has been recognised that the net clearance rate of BLa is $0.1 \text{ mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$ during the passive HT period of a soccer match (Krustrup et al., 2006b). The net clearance rate of $0.07 \text{ mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$ observed during the HT period of the current protocol is therefore comparable to match-play data.

The physiological response is thus within the range observed during match-play across a range of parameters and compares favourably with other experimental models. The prolonged periods of LI associated with match-play negate the accumulation of physiological stress in soccer (Greig et al., 2006). The use of treadmill protocols also limits the opportunity for the inclusion of utility movements and COD which are likely to increase the physical demands (Greig et al., 2006; Dellal et al., 2010; Buchheit et al., 2010; Buchheit et al., 2011; Buglione and di Prampero, 2013; Akenhead et al., 2015), and laboratory-based experimental trials will inherently have a lower emotional stress than competitive match-play (Whitehead et al., 1996), as such, a conservative physiological response might be expected from any treadmill-based SSEP.

Ratings of perceived exertion recorded during the protocol increased from $10 \pm 2 \text{ a.u}$ during the first 15mins to $14 \pm 2 \text{ a.u}$, equivalent to 'Somewhat hard', in the final 15 min bout. Values of 10-15 a.u have been recorded during professional soccer (Scott et al., 2013). The values reported are similar to (Drust et al., 2003) and greater than (Greig et al., 2006) those reported by previous treadmill-based SSEP's, although distances covered varies between protocols.

The physiological response elicited from the current protocol is therefore a valid representation of soccer match-play, elicited from a valid distance and velocity profile. The biomechanical validity gained in modelling a high frequency of speed change elicits a high mechanical demand upon the body (Greig et al., 2006). Due to the methodological issues associated with quantifying biomechanical measures during match-play, it is difficult to evaluate the biomechanical response to the protocol. GPS-mounted tri-axial accelerometry has recently become a popular method of monitoring exercise intensity in both the field and laboratory setting (Boyd et al., 2011; Barrett et al., 2013; Cormack et al., 2013ab; Scott

et al., 2013; Barrett et al., 2014; Barron et al., 2014; Walker et al., 2015). The high sample rate (100 Hz) of the accelerometer in relation to the GPS (typically 5-10 Hz), and the capacity to measure movement in three planes, provides scope to accurately assess the mechanical response to exercise. Tri-axial accelerometry provides a method of quantifying the biomechanical response to exercise, defined as PlayerLoad™ (Boyd et al., 2011). Tri-axial PlayerLoad™ increased significantly from 206.26 ± 13.97 a.u in the first 15 min bout to 216.04 ± 21.39 a.u in the final 15 min bout. These values are comparable to the average tri-axial PlayerLoad™ values ~ 207.5 and ~ 213.5 a.u identified for a 15 min bout of match-play and free-running SSEP respectively (Barrett et al., 2013). It was observed that the greatest increase in the PL_{total} data occurred in the first half of the SSEP. These data therefore support previous observations of the greatest reductions in BF muscle activity and eccentric KF PT occurring during the first half of SSEP's (Rahnama et al., 2006; Greig et al., 2008; Small et al., 2010; Marshall et al., 2014).

Further validation of the cumulative biomechanical response to soccer match-play is limited to date, and the subsequent planar analysis represents an innovative consideration of PlayerLoad™. The increase in PL_{total} was as a result of increases in both PL_{AP} and PL_{ML} as a function of exercise duration, with PL_{AP} and PL_{ML} peaking at 62.02 ± 10.19 a.u and 49.50 ± 6.48 a.u during the last 15 min bout, respectively.

The relative contribution of PL_{AP}% increased linearly from 26.60 ± 3.67 % during the first 15mins to 28.62 ± 3.37 % during the final 15 mins. With no change in the PL_{ML}% at $\sim 23\%$, there was a compensatory decrease in PL_V% from 49.27 ± 7.09 % in the first 15min bout to 47.30 ± 6.47 % in the final 15 min bout. In hierarchical order the mean relative contributions of PL_V%: PL_{AP}%: PL_{ML}% was $\sim 48:28:23$. Similar relative contributions of 44:32:24 have been identified in ARF players in a non-fatigued, and 42:35:23 in a fatigued state (Cormack et al., 2013), and the same fatigue-induced increase in PL_{AP}% and compensatory reduction in PL_V% (Cormack et al., 2013). The percentage change at ~ 2 % as a result of fatigue is also similar in magnitude to the current study. Competitive youth soccer match-play (Barron et al., 2014) elicited PL_{total} values (considering all playing positions) of ~ 100.25 a.u/km, in comparison with the present study at 104.46 a.u/km. Further analysis of the match-play data (Barron et al., 2014) suggests uni-axial contributions of $\sim 44:29:26$, in comparison with 48:28:23 in the present study. The magnitude of, and uni-axial contributions to PL_{total} from the current SSEP is therefore similar to soccer match-play. Greater differences between match-play and treadmill running might be expected given the constrained acceleration and deceleration speeds

($\pm 1.39 \text{ m}\cdot\text{s}^{-2}$) of the treadmill, however, $\sim 93\%$ of the TD covered during match-play occurs within $\pm 2 \text{ m}\cdot\text{s}^{-2}$ (Barron et al., 2014). Although the amount of distance covered at accelerations $> 2 \text{ m}\cdot\text{s}^{-2}$ is relatively small, the inability to achieve these speeds on the treadmill may support the slightly lower PlayerLoadTM values. The lower PL_{ML%} elicited from the treadmill protocol may also be attributable to the exclusion of utility movements from the protocol; however, a recent study comparing a treadmill-based SSEP with a free running SSEP identified that the inclusion of COD did not alter the mechanical response (Raja Azidin et al., 2015). Whilst direct comparisons are limited to date, both the magnitude and uni-axial distribution of PlayerLoadTM suggest a valid representation of the mechanical response to match-play.

Treadmill running protocols are often criticised for being unidirectional, eliciting a linear running style and thus not replicating the movement patterns associated with match-play (Small et al., 2009). The current protocol elicits $\sim 23\%$ of all PlayerLoadTM in the medial-lateral plane. It has previously been identified that 76.3% of all purposeful movements in soccer are performed directly forwards, directly backwards, or in no specific direction (Bloomfield et al., 2007). In support of the current data, $\sim 24\%$ of all purposeful movements are therefore performed with some form of medial-lateral influence (Bloomfield et al., 2007). The high frequency of treadmill speed change (in the anterior-posterior plane) places great demand on acceleration and deceleration mechanics. Although the SSEP is not characterised by extreme cutting manoeuvres or COD, the observed PL_{ML%} suggests that the participants possess a running gait that is characterised by considerable laterality with each foot contact occurring outside of the line of the body. The current velocity profile provides little opportunity for constant velocity movement, with 231 discrete changes in speed during each 15 min bout. This equates to ~ 15 speed changes per minute, and thus the medial-lateral displacement of the body is likely to be functional in initiating acceleration and/or deceleration. This suggests a running style more aligned to agility rather than linear speed, and might be indicative of a functional adaptation in the gait characteristics of these soccer players. The multi-directional and reactive nature of soccer, and the current training emphasis on small-sided games, is likely to induce a running gait functionally suited to agility. This observation warrants further investigation.

GPS-based tri-axial accelerometry has been used to quantify the mechanical response to incremental treadmill running (Barrett et al., 2014). Further analysis of the data presented quantifies PL_{total} at $\sim 76.94 \text{ a.u./km}$, which is substantially lower than the 104.46 a.u./km

elicited in the present study despite the higher average velocity associated with the incremental protocol. Moreover, analysis of the uni-axial PlayerLoadTM data associated with the incremental protocol identified a relative contribution of ~56:23:21. In comparison, the current study elicits a reduced PL_V% response with a compensatory increase in PL_{AP}% and PL_{ML}% (48:28:23), reflecting the differences between incremental and intermittent running. The algorithm associated with the calculation of PlayerLoadTM is based on the instantaneous rate of change in acceleration (Boyd et al., 2011). The SSEP used in the present study is characterised by a HI velocity profile, validated against match-play (Mohr et al., 2003), and thus creates an equivalent PlayerLoadTM response. In comparison, where protocols have utilised prolonged periods of activity (Bishop et al., 1999; Drust, et al., 2000b; Nicholas et al., 2000; Williams et al., 2010; Russell et al., 2011), a valid PlayerLoadTM response would not be expected.

The cumulative fatigue response observed with the acceleometry data mirrors observations of fatigue-induced changes in technique. Previous literature has identified a fatigue effect in agility technique (Greig and Siegler, 2009), functional stability (Greig and Walker-Johnson, 2007) and kicking (Kellis et al., 2006). Soccer-specific activity also induces reductions in eccentric KF strength indicative of muscular fatigue (Greig et al., 2006; Small, et al., 2010). During match-play, acceleration and decelerations capabilities may be compromised as a result of fatigue (Akenhead et al., 2013). If the KF muscles are required to contract eccentrically whilst in a fatigued state, then changes in running technique may occur with the high frequency of speed change. To protect the KF musculature from injury soccer players were observed to decrease stride length (Small et al., 2009), which might be achieved through increased laterality in running technique. This is supported by the observed increases in both PL_{AP} and PL_{ML}. The observed reduction in PL_V is also indicative of a flatter mass centre trajectory during each stride, which could also be achieved by reducing stride length. Laterality during speed change would also increase given the treadmill inclination, and the 2.5% gradient at the highest speed elicits an “up-hill” or “resisted” sprint technique associated with lower stride length. Since the treadmill speed is predetermined, any decrease in stride length must be accompanied, or pre-empted, by an increase in stride frequency. If the observed changes in PlayerLoadTM can be attributed to a change in movement quality then there are likely to be implications for both performance and injury risk, reflecting observations of match-play.

4.5 CONCLUSION

The treadmill protocol is based on the velocity profile of soccer match-play, and elicits a valid physiological and mechanical response. The protocol provides varied opportunities for sport scientists or strength and conditioning coaches, primarily in representing a valid stimulus to develop match fitness without the inherent risk of injury associated with match-play. The velocity profile could be manipulated to provide an overload stimulus, for example by increasing the number of HI efforts within a cluster, or the number of clusters. The activity profile (and/or acceleration) could also be reduced, for applications in youth soccer for example, or in return to play management of injured players. The protocol could also potentially be used as a screening tool, or fitness assessment in pre-season or in late stage rehabilitation. In a training context the treadmill protocol provides a pre-determined and standardised workload, in contrast to the self-paced nature of soccer match-play. The current physiological response is specific to the activity profile and mechanical demands, and in turn this will influence the mechanical response to exercise. Subsequent Chapters in the thesis will therefore consider the influence of different velocity profiles on the physical response to exercise. The fatigue effect evident in the biomechanical response mirrors epidemiological observations of injury incidence (Hawkins et al., 2001; Ekstrand et al., 2011). Subsequent Chapters will therefore also consider additional markers of injury, and the influence of repeated exercise stressors on both injury risk and performance.

CHAPTER FIVE

STUDY TWO

THE BIOMECHANICAL AND PHYSIOLOGICAL RESPONSE TO REPEATED SOCCER-SPECIFIC SIMULATION INTERSPERSED BY 48 OR 72 HOURS RECOVERY

5.1 INTRODUCTION

In the previous chapter the SSEP was demonstrated to offer a valid representation of the velocity profile, distance covered, and the physical response associated with soccer match-play. Subsequently, this protocol can be used to begin to provide answers to questions that are pertinent to contemporary soccer with emphasis surrounding physical performance and injury risk.

Fixture congestion is a contemporary concern within soccer (Carling et al., 2015) with implications for performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014;) and injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015). The most successful teams are often required to compete in the largest number of competitions (Dupont et al., 2010), with the 2015 UEFA champions League winners playing in 60 matches across the 2014-2015 season. Elite teams are therefore characterised by large squads (Carling et al., 2012; Dellal et al., 2015). Squad rotation policies support the notion that coaches recognise the potentially detrimental effects that periods of fixture congestion can have on their players. Due to the high frequency of matches associated with modern soccer (Mohr et al., 2003; Nédélec et al., 2013) players are often required to compete with only two to three days recovery (Dupont et al., 2010; Rollo et al., 2014; Carling et al., 2015; Dellal et al., 2015).

The physical response to (Mohr et al., 2003; Krstrup et al., 2006b) and the time course of recovery from a single bout of soccer-specific activity (Ascensão et al., 2011; Ispirlidis et al., 2008; Magalhães et al., 2010; Rampinini et al., 2011) has been well considered, but not the physical response associated with successive bouts of soccer-specific activity. The majority of literature associated with fixture congestion in soccer has typically used time motion analyses to assess the physical fatigue response (Odetoyinbo et al., 2007; Carling et al., 2010; Dupont et al., 2010; Rey et al., 2010; Lago-Peñas et al., 2011; Carling et al., 2012, Djaoui et al., 2014; Dellal et al., 2015; Folgado et al., 2015). Although soccer match-play offers high ecological validity, there are restrictions on data collection (Rollo et al., 2014; Stølen et al., 2005) and matches are susceptible to contextual factors (Gregson et al., 2010; Rollo et al., 2014). As such, previous literature has often reported equivocal findings in relation to the impact of short-term fixture congestion on injury risk and performance. It has, therefore, recently been suggested that soccer-specific simulations could provide a unique opportunity to assess the physical mechanisms associated with repeated bouts of soccer-specific activity (Carling et al., 2015).

Given the potentially detrimental effects associated with periods of short-term fixture congestion, the aim of this current study was to quantify the physical fatigue response associated with repeated match simulations interspersed by 48 h or 72 h recovery, relevant to the demands of the modern player.

5.2 METHOD

5.2.1 Participants

Twenty male semi-professional soccer players volunteered to complete this study during the English competitive soccer season. The physical and anthropometrical characteristics of the participants are shown in table 5.1. Participant's eligibility was determined from the inclusion and exclusion criteria described in Chapter 3.1. Preliminary anthropometric and health screening procedures were also completed as described in Chapter 3.3. The current study conformed to all ethical considerations described previously in Chapter 3.2.

5.2.2 Experimental design

As presented in table 5.1, participants were matched for: playing position, age, mass, height, and the physical response to a 30 min familiarisation trial. Independent T-tests were conducted for all measures reported in table 5.1, with no significant differences being observed between the two groups (P values ranged between 0.24 to 0.94). Thereafter, one participant from each pair was randomly assigned to the 48 h recovery group ($N = 10$) and one to the 72h recovery group ($N = 10$).

Table 5.1. The physical and anthropometrical characteristics of the two groups (48 h and 72h), and the physical response to a 30 minute familiarisation trial.

	Groups	
	48 hr ($N = 10$)	72hr ($N = 10$)
Age (yrs)	22.10 ± 2.69	21.6 ± 2.12
Height (cm)	176.63 ± 5.80	179.82 ± 6.17
Mass (kg)	74.47 ± 5.68	77.44 ± 8.21
HR ($\text{b} \cdot \text{min}^{-1}$)	146 ± 14	142 ± 11
HR _{peak} ($\text{b} \cdot \text{min}^{-1}$)	162 ± 13	157 ± 12
$\dot{V}\text{O}_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	33.71 ± 2.11	32.71 ± 2.65
$\dot{V}\text{O}_{2\text{peak}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	45.92 ± 3.53	45.79 ± 4.40
BLa ($\text{mmol} \cdot \text{L}^{-1}$)	2.2 ± 0.7	2.2 ± 1.0
PL _{total} (a.u)	209.13 ± 10.59	205.58 ± 12.88
RPE (a.u)	10 ± 1	11 ± 2

Participants attended the laboratory on three occasions to complete a familiarisation trial followed by two experimental trials. A minimum of 96 h interspersed the familiarisation trial and the start of the first experimental trial. Thereafter, the participants then completed the second experimental trial following their prescribed recovery duration (48 or 72 h). The experimental design and controls are described in more detail in chapter 3.4. All trials were completed on a programmable motorised treadmill (Chapter 3.5). The familiarisation trials comprised 2 x 15 min bouts of a SSEP (Chapter 4.2.2) completed under test conditions. Prior to each trial, participants were required to complete a standardised warm-up (chapter 3.6). The experimental trials consisted of the completion of two identical treadmill-based SSEP's (Chapter 4.2.2).

5.2.3 Experimental measures

Additional detail in relation to each measure is provided in chapter 3. The physical measures were chosen to replicate those commonly used to monitor fatigue and training load within an applied sport setting (Halsen, 2014). Average values for HR, HR_{peak}, $\dot{V}O_2$, and $\dot{V}O_{2peak}$ were calculated at rest and for each 15min bout of the experimental protocols (Chapter 3.7.2). Blood lactate concentrations and RPE were also recorded as point readings at rest and immediately following the completion of each 15min bout of the experimental protocols (Chapter 3.7.1). Blood lactate concentrations were also recorded following the completion of the HT period. Average values for PL_{total}, PL_{ML}, PL_{AP}, PL_V, PL_{ML}%, PL_{AP}%, and PL_V% were also calculated for each 15min bout of the experimental trials (Chapter 3.7.3).

5.2.4 Statistical analysis

Statistical analyses and the variables that were to be included were decided *a priori*. Statistical assumptions were checked using the methods described previously in chapter 4. Inferential analyses were performed using a mixed method three-way (group*trial*time) GLM to examine differences in the physical response between the two groups (48 h vs. 72 h of recovery), the two trials, and over time. Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, 95% CI for difference were also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (≥ 0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean \pm SD unless otherwise stated.

5.3 RESULTS

5.3.1 RPE and physiological responses

As identified in table 5.2, the GLM identified significant ($P < 0.001$) main effects for time for BLa ($\eta^2 = 0.34$), $\dot{V}O_2$ ($\eta^2 = 0.99$), $\dot{V}O_{2peak}$ ($\eta^2 = 0.96$), HR ($\eta^2 = 0.97$), and HR_{peak} ($\eta^2 = 0.97$). The GLM did not identify a significant main effects for trial for BLa ($P = 0.76$) and $\dot{V}O_2$ ($P = 0.33$). There were however significant main effect for trial for the HR ($P = 0.02$, $\eta^2 = 0.26$), HR_{peak} ($P = 0.03$, $\eta^2 = 0.24$), and $\dot{V}O_{2peak}$ ($P = 0.05$, $\eta^2 = 0.21$) data. Post hoc pairwise comparisons identified significantly higher values in the first trial ($HR = 140 \pm 13$ b·min⁻¹; $HR_{peak} = 154 \pm 13$ b·min⁻¹; $\dot{V}O_{2peak} = 40.86 \pm 3.58$ ml·kg⁻¹·min⁻¹) when compared to the second ($HR = 137 \pm 13$ b·min⁻¹; $HR_{peak} = 151 \pm 13$ b·min⁻¹; $\dot{V}O_{2peak} = 39.28 \pm 3.67$ ml·kg⁻¹·min⁻¹). The 95% CI for these differences were 0 to 5 b·min⁻¹, 0 to 6 b·min⁻¹, and 0.04 to 3.13 ml·kg⁻¹·min⁻¹ respectively. The GLM did not identify any significant trial*time ($P > 0.05$) interactions for any of the physiological measures.

In direct relation to the fatigue response associated with the two groups (48 vs. 72 h), the GLM did not identify any significant group*trial*time ($P > 0.05$), group*time ($P > 0.05$), nor group*trial ($P > 0.05$) interactions for any of the physiological measurements.

As identified in table 5.2, a similar temporal fatigue response ($P < 0.001$, $\eta^2 = 0.89$) was evident for RPE. There was however no significant ($P = 0.14$) main effect for trial. A significant ($P = 0.003$, $\eta^2 = 0.16$) trial*time interaction was identified for RPE, with post hoc pairwise comparisons revealing significantly higher RPE values recorded at 45-60mins in the second trial ($T_{45-60} = 12 \pm 2$ a.u) when compared to the first trial ($T_{45-60} = 11 \pm 2$ a.u). The 95% CI for this difference was 0 to 1 a.u.

When comparing the influence of recovery duration, the GLM identified that there were no significant group*trial*time ($P = 0.89$), group*time ($P = 0.39$), nor group*trial ($P = 0.96$) interactions associated with the RPE data.

Table 5.2 Temporal fatigue response (irrespective of trial and group) associated with a number of physical measures

Time (mins)	BLa (mmol·L ⁻¹)	HR _{peak} (b·min ⁻¹)	HR (b·min ⁻¹)	$\dot{V}O_{2peak}$ (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_2$ (ml·kg ⁻¹ ·min ⁻¹)	RPE (a.u)
Rest	1.4 ± 0.4	80 ± 10	72 ± 11	9.97 ± 2.19	6.91 ± 1.85	6 ± 0
0-15	3.0 ± 2.4 ^a	159 ± 13 ^a	143 ± 12 ^{ab}	45.34 ± 4.33 ^a	32.74 ± 2.76 ^a	10 ± 2 ^a
15-30	2.6 ± 1.2 ^a	162 ± 13 ^a	149 ± 13 ^{ab}	45.56 ± 5.04 ^a	32.77 ± 3.16 ^a	11 ± 2 ^{ab}
30-45	3.2 ± 2.0 ^a	164 ± 13 ^a	153 ± 14 ^{abc}	46.4 ± 4.65 ^a	33.00 ± 3.12 ^a	12 ± 2 ^{ab}
HT	2.2 ± 1.3 ^a					
45-60	3.5 ± 2.2 ^a	165 ± 15 ^a	146 ± 13 ^{ad}	45.74 ± 4.57 ^a	32.62 ± 3.08 ^a	12 ± 2 ^{abc}
60-75	3.2 ± 1.8 ^a	165 ± 13 ^{ab}	151 ± 13 ^{abf}	44.88 ± 4.87 ^{ad}	32.48 ± 3.23 ^a	13 ± 2 ^{abcf}
75-90	3.8 ± 2.0 ^{ae}	169 ± 14 ^{abc}	156 ± 13 ^{abcfg}	46.8 ± 4.70 ^a	33.07 ± 3.53 ^a	14 ± 3 ^{abcdfg}

^{abcdefg} denote significant differences with Rest, 0-15, 15-30, 30-45, HT, 45-60, and 60-75 respectively.

5.3.2 Mechanical responses

As illustrated by figure 5.1, the GLM identified a significant ($P < 0.001$, $\eta^2 = 0.58$) main effect for time for the PL_{total} data. Post hoc pairwise comparisons associated with the main effects for time are illustrated in table 5.3. The GLM identified no significant ($P = 0.82$) main effect for trial (Trial 1 = 215.33 ± 12.15 a.u; Trial 2: 215.95 ± 15.83 a.u) and no significant ($P = 0.25$) trial*time interaction for the PL_{total} data. In comparing the fatigue response elicited by the two groups, the GLM identified that there were no significant group*trial*time ($P = 0.65$), group*time ($P = 0.13$), nor group*trial ($P = 0.82$) interactions for the PL_{total} data.

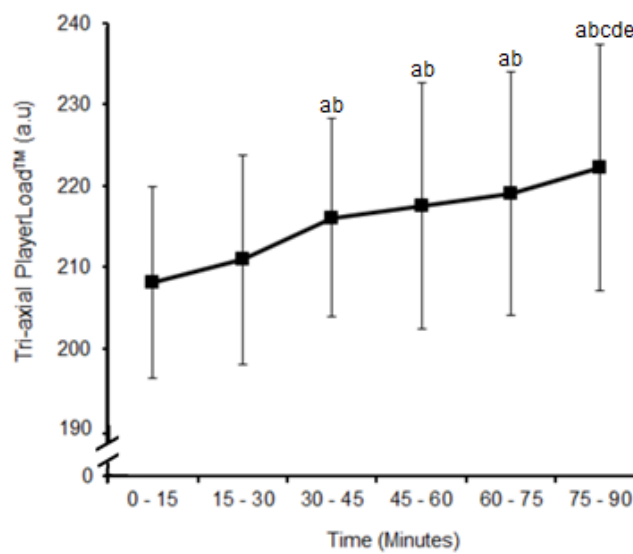


Figure 5.1 Time history of changes (irrespective of group or trial) in the PL_{total} data. a, b, c, d, and e denote significant differences from 0-15 mins, 15-30 mins, 30-45 mins, 45-60 mins, 60-75 mins and 75-90 mins, respectively.

Figure 5.2 illustrates the time history of changes in PL_{AP} , PL_{ML} , and PL_V . In support of the temporal fatigue response evident for the PL_{total} data, the uni-axial PlayerLoad™ data tended to increase across each trial. As depicted in table 5.3, the GLM identified significant main effects for time for PL_{AP} ($P < 0.001$, $\eta^2 = 0.19$), PL_{ML} ($P < 0.001$, $\eta^2 = 0.37$), and PL_V ($P = 0.002$, $\eta^2 = 0.19$) data. The GLM did not identify any significant ($P > 0.05$) main effects for trial, and no significant ($P > 0.05$) trial*time interactions for the PL_{AP} , PL_{ML} , and PL_V data. In relation to the uni-axial PlayerLoad™ response associated with the two groups, the GLM identified that there were no significant group*trial*time ($P > 0.05$), group*time ($P > 0.05$), nor group*trial ($P > 0.05$) interactions for PL_{AP} , PL_{ML} , and PL_V data.

Table 5.3 Temporal fatigue response (irrespective of trial and group) associated with the tri-axial accelerometry data

Time (mins)	PL _{Total} (a.u)	PL _V (a.u)	PL _{ML} (a.u)	PL _{AP} (a.u)	PL _{AP%} (%)	PL _{V%} (%)
0-15	208.08 ± 11.77	107.41 ± 9.62	47.28 ± 5.36	54.12 ± 7.01	26.07 ± 3.35	51.34 ± 3.34
15-30	210.91 ± 12.89	106.74 ± 9.61	48.17 ± 6.04	56.60 ± 7.33 ^a	26.84 ± 3.30 ^a	50.36 ± 3.26 ^a
30-45	216.03 ± 12.20 ^{ab}	108.81 ± 9.12 ^b	49.04 ± 6.10 ^{ab}	58.73 ± 7.78 ^{ab}	27.22 ± 3.42 ^{ab}	50.16 ± 3.40 ^a
45-60	217.56 ± 15.14 ^{ab}	109.81 ± 9.95 ^b	49.26 ± 5.85 ^a	58.84 ± 9.08 ^a	27.07 ± 3.53 ^a	50.47 ± 3.56 ^a
60-75	218.62 ± 15.63 ^{ab}	108.54 ± 9.71	49.65 ± 5.85 ^a	60.80 ± 9.18 ^{abc}	27.79 ± 3.45 ^{abd}	49.56 ± 3.45 ^{abd}
75-90	222.23 ± 15.16 _{abcde}	109.47 ± 10.51	50.06 ± 6.51 ^a	62.03 ± 9.18 ^{abcde}	28.06 ± 3.35 ^{abcd}	49.37 ± 3.49 ^{abcd}

abcde denote significant differences with 0-15, 15-30, 30-45, 45-60, and 60-75 respectively.

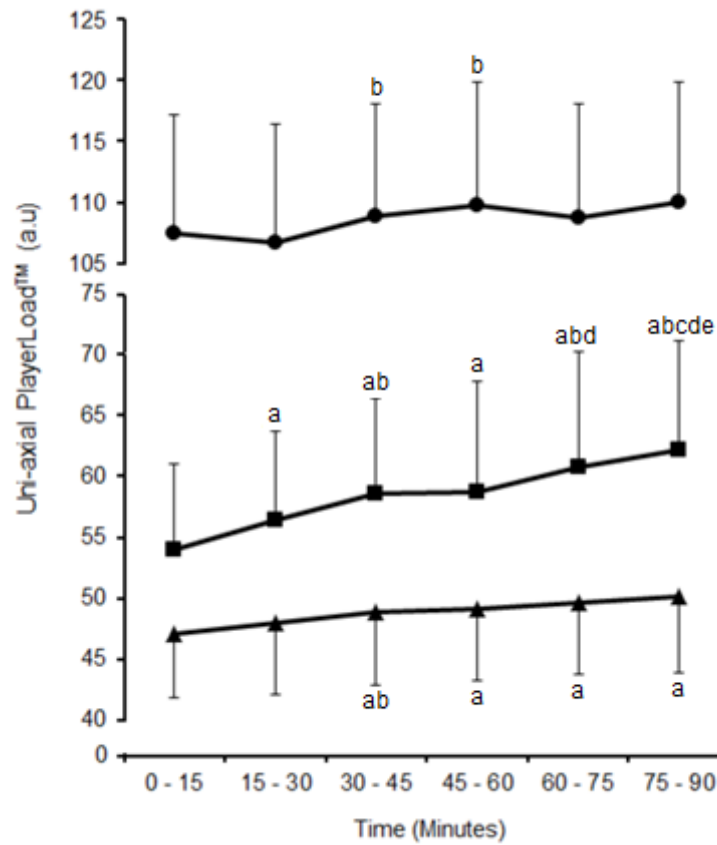


Figure 5.2. Time history of changes (irrespective of group or trial) in the uni-axial PlayerLoad™ vectors (● = PL_V; ■ = PL_{AP}; ▲ = PL_{ML}). a, b, c, d, and e denote significant differences from 0-15 mins, 15-30 mins, 30-45 mins 45-60 mins, and 60-75 mins, respectively.

A similar response was identified for the relative contributions of each uni-axial PlayerLoad™ vector. As identified in table 5.3, significant ($P < 0.001$) main effects for time were identified for both the PL_V% ($\eta^2 = 0.59$) and PL_{AP}% ($\eta^2 = 0.64$). There was however no significant ($P = 0.76$) main effect for time for the PL_{ML}% data, with average values consistent at 22.87 ± 1.56 %. The GLM also did not identify any significant ($P > 0.05$) main effects for trial, and no significant trial*time ($P > 0.05$) interactions for the PL_V%, PL_{ML}%, and PL_{AP}% data. In relation to the fatigue response associated with the two groups, the GLM identified that there were no significant group*trial*time ($P > 0.05$), group*time ($P > 0.05$), nor group*trial ($P > 0.05$) interactions for the PL_V%, PL_{ML}%, and PL_{AP}% data.

5.4 DISCUSSION

Based on recent recommendations (Carling et al., 2015), the aim of the study was to compare the fatigue response associated with successive soccer simulations interspersed by either 48 or 72 h recovery. The current data suggests that (with equivalence at baseline) there was no significant difference in the physical fatigue response elicited by the two groups. A 48 h recovery period is therefore sufficient to recover the physical measures utilised in the current study. The current data supports previous fixture congestion literature that has identified no impairment of physical performance measures (Andersson et al., 2008; Dupont et al., 2010; Rey et al., 2010; Carling and Dupont; Lago-Peñas et al., 2011; Carling et al., 2012; Dajaoui et al., 2013; Folgado et al., 2015; Dellal et al., 2015) and no increased injury risk (Carling et al., 2012), but contrasts other observations of increased injury risk (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015) and reductions in some physical performance measures (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) during congested fixture schedules.

The disparity between previous fixture congestion literature may be attributable to methodological differences, the influence of contextual factors (Rollo et al., 2014), and the large between match variability of commonly used performance parameters (Gregson et al., 2010; Rollo et al., 2014). Reductions in performance during periods of fixture congestion may be indicative of the self-paced nature of soccer match-play, rather than a decrease in physical capacity. Team sport athletes may alter their activity profiles at low intensities in an attempt to preserve their HI running capacity (Smith et al., *In Press*). These altered pacing strategies may also be utilised during periods of short-term fixture congestion (Folgado et al., 2015). Where previous studies have identified an increased injury risk, this may be related to insufficient recovery of other mechanical measures that have not been recorded in the current study.

As expected, a temporal fatigue response was identified for all variables, with the exception of $PL_{ML\%}$ data. The current data therefore supports the reductions in performance (Mohr et al., 2003) and increased injury risk (Ekstrand et al., 2011) observed towards the latter stages of soccer match-play. Supporting both the data reported in study 1 (Chapter 4) and also previous research, values for all physical measures were within the range observed during soccer match-play (Mohr et al., 2003; Stølen et al., 2005; Krstrup et al., 2006b; Scott et al., 2013; Barron et al., 2014; Mohr et al., 2012).

Although there were no significant differences elicited between groups, there were some observed differences between the data recorded in the first and second trials. Values for HR and HR_{peak} were significantly higher in the 1st trial when compared to the 2nd. The difference of 3 b·min⁻¹ (~2%) is less than the variability of 4-6.5% identified in match-play (Andersson et al., 2008; Halson, 2014), and might simply be attributable to a higher stress response elicited from the initial trial. In further support of this, significantly higher $\dot{V}O_{2peak}$ values were also observed in the first trial (40.86 ± 3.58 ml·kg⁻¹·min⁻¹) when compared to the second trial (39.28 ± 3.67 ml·kg⁻¹·min⁻¹). According to Stolen et al., (2005), previous studies have not been able to accurately assess oxygen consumption during match-play and, therefore, the between trial differences observed in the current chapter cannot be compared to typical between match variability.

It was also identified that RPE values were significantly higher in the first 15mins of the second half during the second trial (12 ± 2 a.u) when compared to the first (11 ± 2 a.u). There was no difference in any of the other measures during this period, thus suggesting that the observed differences in the RPE data must be attributable to mechanisms which were not recorded in the current study. The current RPE data supports previous observations of reduced performance (Mohr et al., 2003), reduced muscular function (Greig, 2008), and increased injury risk (Ekstrand et al., 2011) following the completion of a passive HT period. The differences in the RPE data recorded between the two trials may therefore be related to impaired mechanical function.

The current observations of no difference in physical response to 48 vs. 72 h recovery cannot be generalised beyond the measures used. It has been suggested that a 48-72 h recovery period may not be sufficient to recover parameters including, but not limited to, knee ROM (Ispirlidis et al., 2008), 20 m sprint performance (Ascensão et al., 2008; Ispirlidis et al., 2008), Knee flexion peak torque (Andersson et al., 2008; Magalhães et al., 2010), CK (Andersson et al., 2008; Magalhães et al., 2010), CMJ performance (Andersson et al., 2008) and MS (Andersson et al., 2008; Ascensão et al., 2008; Magalhães et al., 2010; Rampinini et al., 2011). These studies have assessed the time course of physical recovery following the completion of soccer-specific activity, but typically fail to consider the influence of incomplete recovery on subsequent performance. In a rare exception, insufficient physical recovery did not influence either the physiological response, or physical performance in a successive bout of match-play (Andersson et al., 2008). Future research should therefore aim to assess the recovery of additional measures during periods of short-term fixture congestion,

as well as assessing the potential impact of these measures on subsequent performance and markers of injury.

5.5 CONCLUSION

Acknowledging the specificity of the physiological and mechanical measures used in the current study (Halsen, 2014); there was no difference in the cumulative and residual fatigue response across the two SSEPs interspersed by either 48 or 72 h recovery. The current findings have implications in the design and micro management of training and competition schedules. The current study is focussed on the physical response associated with a period of short-term fixture congestion; however, future research could utilise the current SSEP to replicate a period of more prolonged fixture congestion. The soccer-specific protocol could also be conducted with additional mechanical measures to mechanistically assess fatigue induced alterations in injury risk during periods of short-term fixture congestion (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015).

CHAPTER SIX

STUDY THREE

THE BIOMECHANICAL AND PHYSIOLOGICAL RESPONSE TO SUCCESSIONAL BOUTS OF DIFFERENT EXERCISE MODALITIES

6.1 INTRODUCTION

Study 2 considered the influence of two bouts of soccer-specific activity with limited recovery between the two bouts (48 vs. 72 h). Acknowledging the specificity of the measures utilised in study 2, it was identified that 48 h was sufficient to recover the measures recorded, with no additional physical demand associated with a successive simulation. However, the nature of athletic training and/or match-play often results in athletes participating in more than two bouts of activity within a weekly cycle. Three games in a week is typically the worst case scenario for a period of short-term fixture congestion (Rollo et al., 2014) with implications for increased injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Nédélec et al., 2012; Dellal et al., 2015) and reductions in physical performance (Odetoyinbo et al., 2007; Carling et al., 2010; Rollo et al., 2014). Study 3 will therefore attempt to assess the cumulative and residual fatigue response associated with the completion of three successive bouts of soccer-specific activity, completed with 48 hrs recovery between each trial.

Soccer has been previously described as an intermittent (Greig et al., 2006) and repeat sprint (Timmins et al., 2014) sport that is characterised by a predominantly aerobic contribution (Reilly and Thomas, 1976; Bangsbo, 1994; Rienzi et al., 2000; Mohr et al., 2003). Soccer match-play is therefore characterised by a complex set of physical demands; a TD of ~10-12 km, an intermittent activity profile, and a repeat-sprint format to the HI bouts. As depicted in figure 6.1 the SSEP protocol utilised in the previous chapters of this thesis could therefore be considered as a hybrid of the continuous 12 km TD covered and the repeated sprint nature of the HI bouts. With respect to soccer-specific conditioning, intermittent, continuous, and repeat-sprint modalities are all used (Morgans et al., 2014). A secondary aim of the present study is, therefore, to assess the physical demand associated with successive bouts of different exercise modalities. The assessment of the discrete characteristics of soccer match-play enables a mechanistic understanding into the cumulative and residual fatigue response associated with a period of short-term fixture congestion.

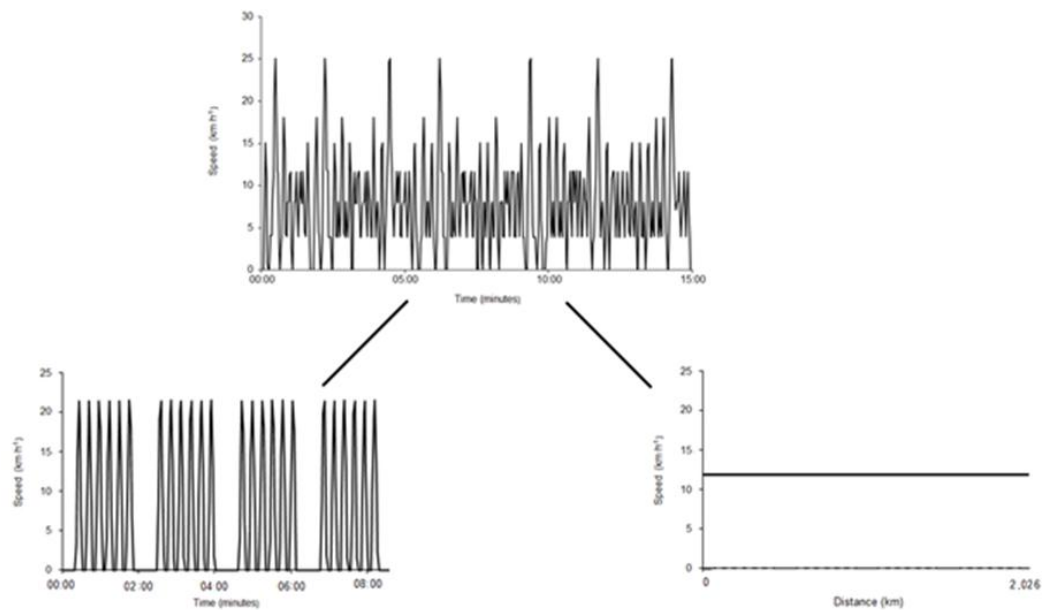


Figure 6.1. The theoretical construct of the SSEP as a hybrid of continuous and repeated sprint demands.

6.2 METHODS

6.2.1 Participants

Ten male semi-professional soccer players (mean \pm SD: age 25.6 ± 3.8 yrs, height 179.0 ± 7.8 cm, body mass 79.0 ± 6.8 kg, $\dot{V}O_{2\max}$ 56.16 ± 5.82 ml \cdot kg $^{-1}$ min $^{-1}$; maximum heart rate 193 ± 8 b \cdot min $^{-1}$; lactate threshold running velocity = 13.0 ± 0.4 km \cdot hr $^{-1}$), volunteered to complete this study during interspersing period between the end of the competitive season and start of pre-season training. Participant's eligibility was determined from the inclusion and exclusion criteria described in Chapter 3.1. Preliminary anthropometric and health screening procedures were also completed as described in Chapter 3.3. The current study conformed to all ethical considerations described previously in Chapter 3.2.

6.2.2 Experimental design

Participants attended the laboratory on twelve occasions to a 30 min familiarisation trial, a combined lactate threshold and $\dot{V}O_{2\max}$ test, another 30 min familiarisation trial, and nine experimental trials. All trials were completed on a programmable motorised treadmill (Chapter 3.5). The preliminary trials (first familiarisation trial, the combined lactate threshold and $\dot{V}O_{2\max}$ test, and the second familiarisation trial) and the start of first experimental trial were all interspersed by 96 h. The nine experimental trials comprised three

SSEP's protocols (INT), three continuous exercise protocols (CONT), and three repeated sprint exercise protocols (RS). The three trials associated with each exercise modality were completed over a 5 day period, with 48 h recovery interspersing each trial. A minimum of 96 h interspersed the completion of each of the 5 day testing periods. The first familiarisation trial comprised 2 x 15 min bouts of the SSEP (Chapter 4.2.2) followed by the completion of an isokinetic strength protocol (Chapter 3.7.5). The second familiarisation trial comprised of the completion of a 30 min continuous run which was completed in similar conditions to the CONT experimental trials. Prior to the commencement of each experimental trial, participants were required to complete a standardised warm-up (Chapter 3.6). The experimental design and controls are described in more detail in chapter 3.4. The three weekly testing periods were conducted in a random order to account for both accommodation and training effects.

6.2.3 Experimental procedures

To determine lactate threshold running velocity ($v\text{-}T_{lac}$), HR_{max} , and $\dot{V}O_{2max}$, participants were required to complete an incremental exercise protocol on a motorised treadmill. The treadmill inclination was set at 1% to account for the lack of air resistance associated with laboratory testing (Jones and Doust. 1996). Participants were fitted with a heart rate monitor (Polar, Team system, Finland) and a breath-by-breath portable metabolic analyser (Cosmed K2, Rome, Italy) for the duration of the protocol. The test was initiated at a running velocity that elicited an average heart rate of ~60% of theoretical heart rate max (McMillan et al., 2005) and comprised 4 minute exercise stages with velocity increasing by 1 km·hr⁻¹ after each stage. A finger-tip capillary blood sample was extracted at the end of each stage and was analysed for blood lactate concentration (Analox Instruments, London, UK). Following the attainment of a blood lactate concentration of 4 mmol·L⁻¹, the test became continuous, whereby, the participants were required to run to volitional exhaustion with the treadmill velocity increasing by 1 km·hr⁻¹ every 2 mins. Software designed to calculate blood lactate endurance markers (Newell, et al., 2007), was used to determine lactate threshold running velocity ($v\text{-}T_{lac}$). The $v\text{-}T_{lac}$ was identified as the first significant increase in blood lactate concentrations above resting levels (Kindermann et al., 1979). Attainment of both $\dot{V}O_{2max}$ and HR_{max} was considered in line with the end-point criteria guidelines of the British association of Sport and Exercise Sciences (Winter et al., 2007).

As previously described in Chapter 4.2.2, the INT exercise protocol consisted of the completion of a treadmill-based SSEP (Figure 6.3). The RS exercise protocol comprised six

identical 8.5 min bouts of activity. Each bout was characterised by four clusters of six sprints interspersed by passive recovery. The structure of the activity period was designed to replicate a repeat sprint training session encompassing the total number, and clustering of sprints, as opposed to a TD of ~12 km or 90 min duration. The activity profile elicited a 1:2 ratio in work ($>0 \text{ km}\cdot\text{h}^{-1}$) to passive recovery duration. The sprint clusters elicited a 1:1 work to passive recovery ratio, with a 1:4 ratio in HI ($>15 \text{ km}\cdot\text{h}^{-1}$) to LI work duration. The sprint phase was assigned a maximal running speed of $21.5 \text{ km}\cdot\text{h}^{-1}$. The maximum treadmill acceleration (and deceleration) of $1.39 \text{ m}\cdot\text{s}^{-2}$ was applied to each sprint phase, with the duration of speed change factored into the duration of each phase. During each sprint phase, time spent at maximal running velocity was 2.0s, thus replicating the mean duration of the sprint phases associated with the INT protocol and intermittent team sports (Spencer et al., 2004). The RS protocol was conducted with varying levels of gradient to account for the lack of air resistance associated with laboratory testing (Jones and Doust, 1996), to replicate the gradient changes associated with the INT protocol, and to elicit an increased physical demand. During the passive recovery periods the treadmill gradient was set at 1%, whereas during the sprint phases the gradient increased to 2.5%. Figure 6.2 provides a schematic representation of the RS velocity profile.

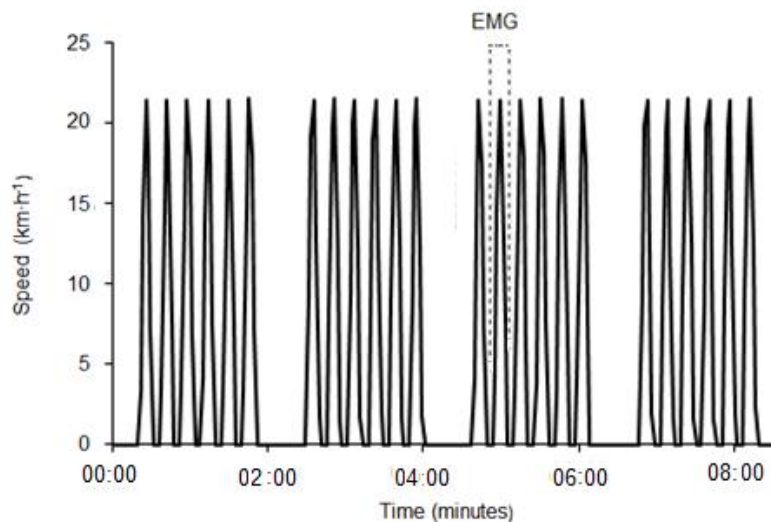


Figure 6.2 Schematic representation of a single bout of the RS protocol. The dashed line indicates the EMG data collection period.

To ensure the exercise protocols were designed as ecologically valid versions of their training modalities, rather than conduct CONT over 90 mins, the performance objective was to cover the same TD (12.16 km), not duration of the INT protocol. Participants were instructed to

complete the required distance in the fastest possible time, and began the first trial at their v_{lac} . The starting velocity of the participants was $13.01 \pm 0.36 \text{ km}\cdot\text{hr}^{-1}$. The participants were aware of their starting velocity and were informed of their distance covered every $\sim 2.03 \text{ km}$. Participants were not provided with any other feedback during the completion of the CONT trials. Running velocity was dictated by the participants and was manipulated as and when required. The velocity profile completed by the participants during their first CONT trial was recorded and repeated for their subsequent CONT trials. The average completion time for the CONT trial was $68:37 \pm 4:33 \text{ mins}$. Similar to the RS and INT trials, the treadmill gradient was maintained at 1% throughout the CONT trial to elicit and increased physical demand and also account for the lack of air resistance associated with laboratory testing (Jones and Doust, 1996).

6.2.4 Experimental measures

Additional detail in relation to some of the measures is provided in Chapter 3. Values for HR, HR_{peak} , $\dot{\text{V}}\text{O}_2$, and $\dot{\text{V}}\text{O}_{2\text{peak}}$ were calculated at rest and for every 2.03 km covered during both the INT and CONT trials, and at rest and for every bout during the RS trials (Chapter 3.7.2). Participants RPE was also recorded every 2.03 km covered during the CONT and INT trials, and immediately following each bout during the completion of the RS trials. Average values for PL_{total} , PL_{ML} , PL_{AP} , PL_{V} , $\text{PL}_{\text{ML}\%}$, $\text{PL}_{\text{AP}\%}$, and $\text{PL}_{\text{V}\%}$ were also calculated for every 2.03km covered during both the INT and CONT trials, and for every bout completed during the RS trials (Chapter 3.7.3). All tri-axial accelerometry data was standardised for distance covered. A fingertip capillary blood sample was analysed for BLa concentrations at rest and immediately following the completion of each experimental trial (Chapter 3.7.1).

Participants provided their perceptions of lower limb muscle soreness MS pre- and post-trials using a VAS scale. The method associated with the MS data is provided in chapter 3.7.4.

Values for EMG_{mean} were quantified from the dominant BF muscle at pre-determined periods during the completion of each trial. Additional detail in relation to the EMG data collection and analysis has been provided previously in chapter 3.7.6. During the completion of the INT trials, data collection was constrained to a standardised period of activity (incorporating a single $25 \text{ km}\cdot\text{h}^{-1}$ bout of running) during each 15 min bout (figure 6.3). During the CONT trials, the data collection occurred at the same distance covered as that associated with the INT trial, and were recorded for the same duration. Similarly, during the RS trials the EMG data collection occurred during the second to last sprint cluster in each bout of activity (figure

6.2). This period of data collection encompassed a single sprint effort and was recorded for the same duration as that associated with both the INT and CONT trial.

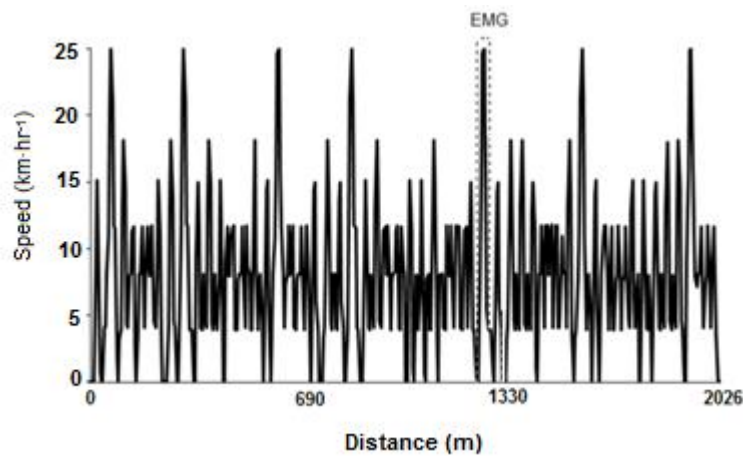


Figure 6.3 Schematic representation of a single 15min bout of the SSEP. The dashed line indicates the EMG data collection period.

Isokinetic dynamometry was also recorded pre- and post-trial to provide values of gravity corrected eccentric KF PT at both ‘fast’ 300 deg·s⁻¹ and ‘slow’ 60 deg·s⁻¹ angular velocities. The isokinetic protocol has been described in more detail in chapter 3.7.5.

6.2.5 Statistical analysis

Statistical analyses and the variables that were to be included were decided *a priori*. Statistical assumptions were checked using standard graphical methods (Grafen and Hails, 2002). A two-factor (trial*time) GLM was employed to examine differences in the physical response associated with the three trials (trial 1, 2, and 3) for each modality (INT, CONT, and RS). A three-factor (modality*trial*time) GLM was also employed to examine differences between the three modalities, the three trials, and over time. The EMG_{mean} data was not compared across modalities because of differences in the running velocities at which the data was recorded. Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, 95% CI for difference were also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (≥ 0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean \pm SD unless otherwise stated.

6.3 RESULTS

6.3.1 RPE and physiological response

- INT

As identified in table 6.1, the GLM identified significant ($P < 0.001$) main effects for time for the $\dot{V}O_2$ ($\eta^2 = 0.99$), $\dot{V}O_{2\text{peak}}$ ($\eta^2 = 0.98$), HR ($\eta^2 = 0.97$), HR_{peak} ($\eta^2 = 0.98$), and RPE data ($\eta^2 = 0.61$). Significantly ($P < 0.001$, $\eta^2 = 0.42$) higher BLa values were also identified post-trial ($3.6 \pm 2.4 \text{ mmol}\cdot\text{L}^{-1}$) when compared to pre-trial ($1.3 \pm 0.3 \text{ mmol}\cdot\text{L}^{-1}$). The 95% CI for this difference was 1.2 to $3.4 \text{ mmol}\cdot\text{L}^{-1}$. There was however no significant ($P > 0.05$) main effects for trial, and no significant ($P > 0.05$) trial*time interactions associated with the aforementioned variables.

- RS

As identified in table 6.1, a similar response was observed in the RS modality whereby the GLM identified significant main effects for time associated with the $\dot{V}O_2$ ($P < 0.001$, $\eta^2 = 0.99$), $\dot{V}O_{2\text{peak}}$ ($P < 0.001$, $\eta^2 = 0.99$), HR ($P < 0.001$, $\eta^2 = 0.97$), HR_{peak} ($P < 0.001$, $\eta^2 = 0.98$), and RPE ($P = 0.004$, $\eta^2 = 0.56$) data. Significantly ($P = 0.002$, $\eta^2 = 0.66$) higher BLa values were also identified post-trial ($3.1 \pm 1.7 \text{ mmol}\cdot\text{L}^{-1}$) when compared to pre-trial ($1.4 \pm 0.4 \text{ mmol}\cdot\text{L}^{-1}$). The 95% CI for this difference was 0.8 to $2.6 \text{ mmol}\cdot\text{L}^{-1}$. There was however no significant ($P > 0.05$) main effects for trial, and no significant ($P > 0.05$) trial*time interactions associated with the aforementioned variables.

- CONT

As identified in table 6.1, by the GLM identified significant main effects for time for the $\dot{V}O_2$ ($P < 0.001$, $\eta^2 = 0.97$), $\dot{V}O_{2\text{peak}}$ ($P < 0.001$, $\eta^2 = 0.97$), HR ($P < 0.001$, $\eta^2 = 0.99$), HR_{peak} ($P < 0.001$, $\eta^2 = 0.97$), and RPE ($P = 0.001$, $\eta^2 = 0.65$) data. Significantly ($P = 0.002$, $\eta^2 = 0.77$) higher BLa values were also identified post-trial ($6.1 \pm 3.4 \text{ mmol}\cdot\text{L}^{-1}$) when compared to pre-trial ($1.3 \pm 0.3 \text{ mmol}\cdot\text{L}^{-1}$). The 95% CI for this difference was 2.8 to $6.7 \text{ mmol}\cdot\text{L}^{-1}$.

With the exception of the HR data, there were no significant ($P > 0.05$) main effects for trial associated with the aforementioned variables. Post hoc pairwise comparisons identified significantly ($P = 0.02$, $\eta^2 = 0.38$) higher HR values in the first trial ($159 \pm 40 \text{ b}\cdot\text{min}^{-1}$) when compared to the third ($152 \pm 37 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for this difference was 1 to $13 \text{ b}\cdot\text{min}^{-1}$.

The GLM also identified a significant ($P < 0.001$, $\eta^2 = 0.41$) trial*time interaction for the RPE data, with significantly higher values being identified in the second and third bouts ($T_2 = 14 \pm$

2 a.u; $T_3 = 14 \pm 2$ a.u) of the third trial when compared to the second trial ($T_2 = 13 \pm 2$ a.u; $T_3 = 14 \pm 2$ a.u). The 95% CI for these differences were 0 to 2 a.u and 0 to 2 a.u, respectively. Furthermore, significantly higher values were observed in the final bout of the first trial (18 ± 1 a.u) when compared to the second (16 ± 3 a.u) and third trials (16 ± 3 a.u). The 95% CI for these differences was 0 to 5 a.u.

The GLM also identified significant trial*time interactions for the $\dot{V}O_2$ ($P = 0.01$, $\eta^2 = 0.32$) and the $\dot{V}O_{2peak}$ ($P = 0.02$, $\eta^2 = 0.26$) data. Post hoc pairwise comparisons identified significantly higher $\dot{V}O_2$ and $\dot{V}O_{2peak}$ values in the second bout ($\dot{V}O_2 = 40.45 \pm 5.48$ ml·kg⁻¹·min⁻¹; $\dot{V}O_{2peak} = 47.74 \pm 5.86$ ml·kg⁻¹·min⁻¹) of the third trial when compared to the second trial ($\dot{V}O_2 = 38.06 \pm 6.24$ ml·kg⁻¹·min⁻¹; $\dot{V}O_{2peak} = 45.93 \pm 6.51$ ml·kg⁻¹·min⁻¹). The 95% CI for these differences were 0.23 to 6.13 ml·kg⁻¹·min⁻¹ and 0.46 to 6.84 ml·kg⁻¹·min⁻¹, respectively. Significantly higher $\dot{V}O_{2peak}$ values were also observed in the final two bouts of the first trial ($T_5 = 45.93 \pm 6.89$ ml·kg⁻¹·min⁻¹; $T_6 = 44.89 \pm 6.53$ ml·kg⁻¹·min⁻¹) when compared to the second trial ($T_5 = 42.32 \pm 6.30$ ml·kg⁻¹·min⁻¹, $T_6 = 41.46 \pm 8.72$ ml·kg⁻¹·min⁻¹). The 95% CI for these differences were 0.37 to 6.87 ml·kg⁻¹·min⁻¹ and 0.13 to 6.72 ml·kg⁻¹·min⁻¹, respectively.

Table 6.1 Time course of changes (irrespective of trial) in $\dot{V}O_2$, $\dot{V}O_{2peak}$, HR, HR_{peak} , and RPE for each of the modalities.

		Rest	Bout 1	Bout 2	Bout 3	Bout 4	Bout 5	Bout 6
$\dot{V}O_2$ (ml·kg ⁻¹ ·min ⁻¹)	INT	6.72 ± 1.43	29.03 ± 3.87 ^{a*}	28.84 ± 3.66 ^{a*}	28.92 ± 3.88 ^{a*}	28.95 ± 3.74 ^{a*}	28.71 ± 3.85 ^{a*}	29.10 ± 3.83 ^{a*}
	RS	6.95 ± 1.96	26.47 ± 2.44 ^{a*}	26.26 ± 2.14 ^{a*}	26.39 ± 2.30 ^{a*}	26.23 ± 2.49 ^{a*}	26.04 ± 2.61 ^{a*#}	26.09 ± 2.58 ^{a*}
	CONT	6.43 ± 1.96	38.74 ± 2.44 ^a	39.59 ± 2.14 ^a	38.01 ± 2.30 ^a	34.95 ± 2.49 ^{abc}	33.63 ± 2.61 ^{abcd}	34.28 ± 2.58 ^{abc}
$\dot{V}O_{2peak}$ (ml·kg ⁻¹ ·min ⁻¹)	INT	10.07 ± 1.83	40.50 ± 5.32 ^{a*}	40.12 ± 5.32 ^{a*}	40.49 ± 6.34 ^{a*}	41.04 ± 5.27 ^a	39.58 ± 4.51 ^a	41.15 ± 5.25 ^a
	RS	10.18 ± 2.35	40.55 ± 2.91 ^{a*}	39.98 ± 3.29 ^{a*}	40.07 ± 3.19 ^{a*}	40.28 ± 3.05 ^a	39.32 ± 3.44 ^a	39.76 ± 3.54 ^a
	CONT	9.85 ± 2.56	46.29 ± 5.59 ^a	47.26 ± 6.12 ^a	45.90 ± 5.80 ^a	45.00 ± 6.20 ^a	44.03 ± 6.04 ^a	43.76 ± 6.50 ^a
HR (b·min ⁻¹)	INT	67 ± 12	136 ± 13 ^{a*}	141 ± 12 ^{ab*}	144 ± 13 ^{abc*}	139 ± 13 ^{a*}	144 ± 13 ^{abde*}	148 ± 13 ^{abcef*}
	RS	63 ± 10	134 ± 15 [*]	139 ± 14 [*]	143 ± 14 ^{abc*}	146 ± 17 ^{abc*}	148 ± 16 ^{abcd*}	149 ± 16 ^{abcd*}
	CONT	67 ± 12	164 ± 10	172 ± 8 ^{ab}	173 ± 9 ^{ab}	171 ± 11 ^{ab}	170 ± 11 ^{ab}	172 ± 11 ^{ab}
HR_{peak} (b·min ⁻¹)	INT	75 ± 12	157 ± 14 ^{a*}	157 ± 15 ^{a*}	159 ± 13 ^{a*}	158 ± 15 ^{a*}	159 ± 12 ^{a*}	164 ± 14 ^{af*}
	RS	73 ± 10	153 ± 16 ^{a*}	157 ± 15 ^{a*}	158 ± 15 ^{a*}	159 ± 16 ^{a*}	162 ± 14 ^{a*}	163 ± 14 ^{af*}
	CONT	80 ± 21	176 ± 10 ^a	179 ± 8 ^a	180 ± 10 ^a	180 ± 7 ^a	180 ± 10 ^a	183 ± 12 ^a
RPE (a.u)	INT		11 ± 2 [*]	12 ± 2 [*]	12 ± 2 ^{bc*}	12 ± 2 ^{b*}	13 ± 2 ^{bc*}	14 ± 2 ^{bcef*}
	RS		10 ± 2 [*]	11 ± 2 [*]	11 ± 2 ^{#*}	12 ± 2 [*]	12 ± 2 [*]	13 ± 2 ^{cd*}
	CONT		12 ± 2	14 ± 2 ^a	15 ± 2 ^a	15 ± 2 ^a	16 ± 2 ^a	17 ± 2 ^a

^{abcdefg} Denotes significant difference from rest, bout 1, bout 2, bout 3, bout 4, bout 5, and bout 6 respectively. * Denotes a significant difference with the CONT modality. # Denotes a significant difference with the INT modality.

A significant ($P= 0.02$, $\eta^2 = 0.30$) trial*time interaction was also identified for the HR data. As identified in figure 6.5, significantly higher HR values were identified in the third ($179 \pm 10 \text{ b}\cdot\text{min}^{-1}$), fourth ($176 \pm 11 \text{ b}\cdot\text{min}^{-1}$), fifth ($175 \pm 13 \text{ b}\cdot\text{min}^{-1}$), and sixth ($178 \pm 13 \text{ b}\cdot\text{min}^{-1}$) bouts of the first trial when compared to the third trial ($T_3= 168 \pm 7 \text{ b}\cdot\text{min}^{-1}$; $T_4= 165 \pm 8 \text{ b}\cdot\text{min}^{-1}$; $T_5= 165 \pm 10 \text{ b}\cdot\text{min}^{-1}$; $T_6= 166 \pm 10 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for these differences were 3 to 20 $\text{b}\cdot\text{min}^{-1}$, 3 to 19 $\text{b}\cdot\text{min}^{-1}$, 1 to 20 $\text{b}\cdot\text{min}^{-1}$, and 3 to 21 $\text{b}\cdot\text{min}^{-1}$ respectively. Significantly lower HR values were also identified in the final bout of the third trial ($166 \pm 10 \text{ b}\cdot\text{min}^{-1}$) when compared to the second trial ($173 \pm 9 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for this difference was -12 to -1 $\text{b}\cdot\text{min}^{-1}$.

- COMPARISON OF MODALITIES

BLa

The GLM identified a significant ($P= 0.01$, $\eta^2 = 0.38$) main effects for modality, with significantly higher values being observed in the CONT modality ($3.7 \pm 3.4 \text{ mmol}\cdot\text{L}^{-1}$) when compared to the RS modality ($2.2 \pm 1.5 \text{ mmol}\cdot\text{L}^{-1}$). The 95% CI for this difference was 0.11 to 2.94 $\text{mmol}\cdot\text{L}^{-1}$. The GLM also identified a significant ($P= 0.01$, $\eta^2 = 0.40$) modalities*time interaction, with significantly higher values being observed post-trial during the CONT modality ($6.1 \pm 3.4 \text{ mmol}\cdot\text{L}^{-1}$) when compared to RS trial ($3.1 \pm 1.7 \text{ mmol}\cdot\text{L}^{-1}$). The 95% CI for this difference was 0.1 to 5.9 $\text{mmol}\cdot\text{L}^{-1}$. There was however no significant modalities*trial ($P= 0.10$), or modalities*trial*time ($P= 0.06$) interactions.

HR and HR_{peak}

The GLM identified a significant ($P< 0.001$) main effect for modality for the HR ($\eta^2 = 0.85$) and HR_{peak} data, with significantly higher values in the CONT modality (HR= $155 \pm 38 \text{ b}\cdot\text{min}^{-1}$; HR_{peak}= $165 \pm 37 \text{ b}\cdot\text{min}^{-1}$) when compared to the INT (HR= $131 \pm 30 \text{ b}\cdot\text{min}^{-1}$; HR_{peak}= $147 \pm 32 \text{ b}\cdot\text{min}^{-1}$) and RS modality (HR= $132 \pm 32 \text{ b}\cdot\text{min}^{-1}$; HR_{peak}= $147 \pm 33 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for these differences were 15 to 33 $\text{b}\cdot\text{min}^{-1}$ and 14 to 33 $\text{b}\cdot\text{min}^{-1}$ for the HR data, and 8 to 29 $\text{b}\cdot\text{min}^{-1}$ and 6 to 32 $\text{b}\cdot\text{min}^{-1}$ for the HR_{peak} data.

As identified in table 6.1, a significant Modalities*Time interaction was also identified HR ($P< 0.001$, $\eta^2 = 0.74$) and HR_{peak} ($P= 0.003$, $\eta^2 = 0.39$) data. There was however no significant Modalities*Trial ($P>0.05$), or Modalities*Trial*Time ($P> 0.05$) interactions.

RPE

A significant ($P < 0.001$, $\eta^2 = 0.69$) main effect for modality was identified, with significantly higher values being observed in the CONT modality (15 ± 3 a.u) when compared to both the INT (12 ± 2 a.u) and RS (12 ± 2 a.u) modalities. The 95% CI for these differences were 1 to 4 a.u and 1 to 5 a.u, respectively. As identified in table 6.1, a significant ($P = 0.01$, $\eta^2 = 0.46$) Modalities*Time interaction was also identified.

The GLM also identified a significant modalities*trial ($P = 0.04$, $\eta^2 = 0.34$) interaction, with significantly higher values in all three CONT trials (Trial₁ = 15 ± 2 a.u; Trial₂ = 14 ± 2 a.u; Trial₃ = 15 ± 2 a.u) when compared to RS modality (Trial₁ = 12 ± 2 a.u; Trial₂ = 12 ± 2 a.u; Trial₃ = 12 ± 2 a.u). The 95 % CI for these differences were 2 to 6 a.u, 0 to 4 a.u, 1 to 5 a.u, respectively. Furthermore, significantly higher RPE values were recorded in the first two CONT trials when compared to the INT (Trial₁ = 12 ± 2 a.u; Trial₂ = 12 ± 2 a.u). The 95% CI for these differences were 2 to 5 and 0 to 3 a.u, respectively.

The GLM also identified a significant ($P = 0.04$, $\eta^2 = 0.35$) modalities*trial*time interactions for the RPE data. The time courses of changes in the RPE data across each modality and trial, and the post hoc comparisons are depicted in table 6.2.

Table 6.2 Time course of changes in the RPE data across each trial for each of the three modalities

	Bout 1	Bout 2	Bout 3	Bout 4	Bout 5	Bout 6
INT 1	11 ± 2 *	11 ± 2 *	12 ± 2 *	12 ± 2 *	13 ± 2 *	14 ± 2 *
INT 2	11 ± 2	11 ± 2 *	12 ± 2 *	12 ± 2 *	13 ± 3	14 ± 2
INT 3	11 ± 2	12 ± 3 *	13 ± 3 *	13 ± 2	13 ± 2	14 ± 2
RS 1	10 ± 2 *	11 ± 2 *	11 ± 2 *	12 ± 2 *	12 ± 2 *	13 ± 2 *
RS 2	10 ± 2 *	11 ± 2 *	12 ± 2 *	12 ± 2 *	13 ± 2	13 ± 2
RS 3	10 ± 2 *	11 ± 2 *	11 ± 2 *	12 ± 2 *	13 ± 2	13 ± 2
CONT 1	12 ± 2	14 ± 2	15 ± 1	16 ± 1	17 ± 1	18 ± 1
CONT 2	12 ± 3	13 ± 2	14 ± 2	15 ± 2	15 ± 2	16 ± 3
CONT 3	12 ± 3	14 ± 2	14 ± 2	15 ± 2	16 ± 2	16 ± 3

*Denotes a significant difference with the CONT modality

$\dot{V}O_{2Peak}$

The GLM identified a significant ($P = 0.01$, $\eta^2 = 0.44$) main effect for modality, with significantly higher values in the CONT modality (57.66 ± 20.81 ml·min⁻¹·kg⁻¹) when

compared to the RS modality ($42.31 \pm 13.90 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). The 95% CI for this difference was 0.03 to $8.79 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$. As depicted in table 6.1, a significant ($P < 0.001$, $\eta^2 = 0.43$) modalities*time interaction was also identified.

As identified in figure 6.4, a significant ($P = 0.03$, $\eta^2 = 0.22$) modalities*trial*time interaction was also identified. Post hoc pairwise comparisons identified significantly higher $\dot{V}O_{2\text{peak}}$ values recorded at bouts 2 and 3 in the first CONT trial ($T_2 = 48.10 \pm 5.99 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; $T_3 = 47.16 \pm 5.54 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) and bouts 1 and 2 ($T_1 = 48.33 \pm 5.48 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; $T_2 = 47.74 \pm 5.86 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) in the third CONT trial when compared to the INT (Trial 1₂ = $38.81 \pm 4.59 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 1₃ = $40.49 \pm 6.33 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 3₁ = $39.23 \pm 6.19 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 3₂ = $39.27 \pm 7.07 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) and RS modality (Trial 1₂ = $38.82 \pm 3.83 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 1₃ = $38.67 \pm 4.43 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 3₁ = $40.63 \pm 1.97 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; Trial 3₂ = $39.52 \pm 2.80 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). Significantly higher values were also identified in bout 1 of the first CONT trial ($45.85 \pm 5.51 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) when compared to the RS modality ($38.84 \pm 3.73 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). The 95% CI for this difference was 1.00 to $13.02 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$. There was however no significant modalities*trial ($P = 0.17$) interactions.

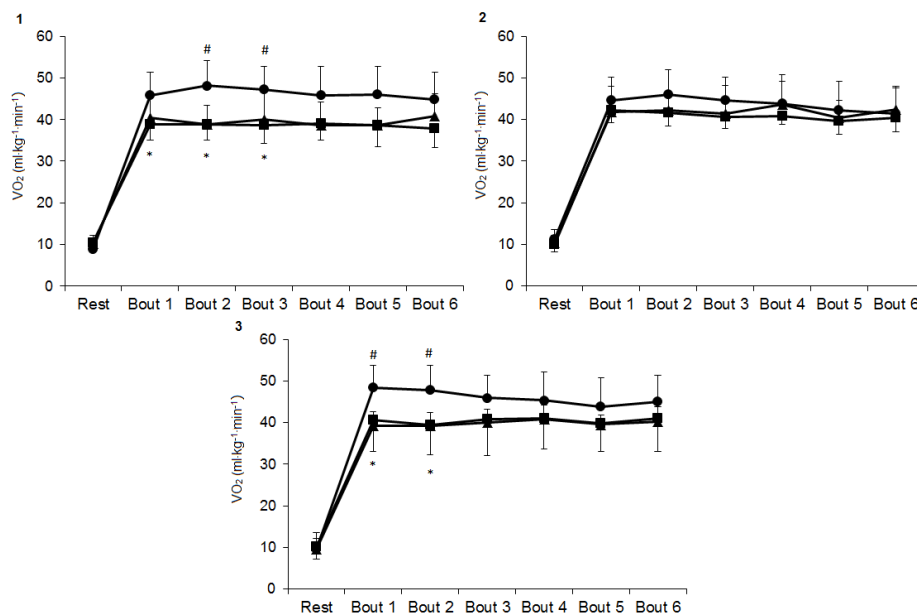


Figure 6.4 Time course of changes in the $\dot{V}O_{2\text{peak}}$ data across each trial (1, 2, and 3) for the three modalities (■ = RS; ▲ = INT; ● = CONT). # denotes a significant difference with the INT modality. * denotes a significant difference with the CONT modality.

$\dot{V}O_2$

The GLM identified a significant ($P < 0.001$, $\eta^2 = 0.78$) main effect for modality, with significantly higher values in the CONT modality ($32.23 \pm 11.70 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) when compared to the INT ($25.75 \pm 8.57 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) and RS modality ($23.49 \pm 7.18 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). The 95% CI for these differences were 2.95 to 10.01 $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ and 4.99 to 12.50 $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$.

As identified in table 6.1, a significant ($P < 0.001$, $\eta^2 = 0.77$) modalities*time interaction was identified for the $\dot{V}O_2$ data. Furthermore, as identified in table 6.3, a significant ($P < 0.001$, $\eta^2 = 0.30$) Modalities*Trial*Time interaction was also identified.

Table 6.3 Time course of changes in the $\dot{V}O_2$ response across each trial for each of the three modalities.

	Rest	Bout 1	Bout 2	Bout 3	Bout 4	Bout 5	Bout 6
INT 1	6.79 \pm 1.72	29.08 \pm 4.23 *	28.11 \pm 3.84 *	28.36 \pm 4.45 *	28.64 \pm 3.84 *	28.06 \pm 3.84 *	28.03 \pm 4.09 *
INT 2	7.10 \pm 1.14	30.17 \pm 2.71 *	29.78 \pm 2.47 *	29.75 \pm 2.48 *	29.84 \pm 2.22	29.48 \pm 2.64	29.82 \pm 2.19
INT 3	6.28 \pm 1.41	27.85 \pm 4.68 *	28.61 \pm 4.67 *	28.65 \pm 4.70 *	28.37 \pm 5.17 *	28.58 \pm 5.09 *	29.44 \pm 5.19
RS 1	7.38 \pm 1.95	25.39 \pm 2.21 *	25.45 \pm 2.37 *	25.27 \pm 2.04 *	24.95 \pm 2.12 *	24.95 \pm 2.12 *	24.79 \pm 2.22 *
RS 2	7.03 \pm 1.21	26.81 \pm 2.59 *#	27.00 \pm 2.05 *#	27.24 \pm 2.30 *#	26.89 \pm 2.66 *#	26.28 \pm 2.83 *#	26.56 \pm 2.64 *#
RS 3	6.44 \pm 2.72	27.21 \pm 2.52 *	26.32 \pm 1.99 *	26.66 \pm 2.56 *	26.86 \pm 2.68 *	26.88 \pm 2.89 *	26.92 \pm 2.88 *
CONT 1	6.03 \pm 1.85	38.67 \pm 4.63	40.26 \pm 5.32	39.56 \pm 5.77	35.81 \pm 6.27	34.50 \pm 4.57	35.27 \pm 5.88
CONT 2	6.82 \pm 2.15	37.18 \pm 4.74	38.06 \pm 6.24	37.20 \pm 5.94	34.81 \pm 5.42	33.12 \pm 3.85	33.73 \pm 5.19
CONT 3	6.44 \pm 1.04	40.36 \pm 3.39	40.45 \pm 5.48	37.28 \pm 5.60	34.25 \pm 3.95	33.28 \pm 2.63	33.86 \pm 3.53

Denotes a significant difference with the INT modality. * Denotes a significant difference with the CONT modality.

6.3.2 Accelerometry responses

- INT

As identified in table 6.4, there were significant main effects for time associated with PL_{total} ($P= 0.004$, $\eta^2 = 0.43$), PL_{AP} ($P< 0.001$, $\eta^2 = 0.67$), PL_V ($P= 0.004$, $\eta^2 = 0.24$), $PL_{AP\%}$ ($P< 0.001$, $\eta^2 = 0.70$), and $PL_{V\%}$ ($P< 0.001$, $\eta^2 = 0.56$). There were however no significant main effects for time for PL_{ML} ($P= 0.46$) and $PL_{ML\%}$ ($P= 0.23$). Average values for PL_{ML} and $PL_{ML\%}$ were consistent at 25.65 ± 3.93 a.u and 24.10 ± 2.12 %, respectively.

There was also no significant ($P> 0.05$) main effects for trial, and no significant ($P> 0.05$) time*trial interactions for any of the accelerometry measures.

- RS

As identified in table 6.4, the GLM identified no significant main effects for time for the PL_{total} ($P= 0.16$), PL_V ($P= 0.06$), PL_{ML} ($P= 0.25$), $PL_{ML\%}$ ($P= 0.14$), $PL_{AP\%}$ ($P= 0.33$), and $PL_{V\%}$ ($P= 0.17$). There was a significant ($P= 0.02$, $\eta^2 = 0.29$) main effect for time associated with the PL_{AP} data.

There was however no significant main effects for trial ($P> 0.05$) and no significant trial*time ($P> 0.05$) interactions associated with any of the accelerometry measures.

- CONT

As identified in table 6.4, there were significant main effects for time associated with PL_{total} ($P= 0.01$, $\eta^2 = 0.42$), PL_{AP} ($P= 0.03$, $\eta^2 = 0.35$), PL_V ($P= 0.03$, $\eta^2 = 0.36$), and PL_{ML} ($P< 0.001$, $\eta^2 = 0.47$). There were however no significant main effects for time for $PL_{AP\%}$ ($P= 0.15$), $PL_{V\%}$ ($P= 0.51$), and $PL_{ML\%}$ ($P= 0.16$). Average values for $PL_{AP\%}$, $PL_{V\%}$, and $PL_{ML\%}$ were consistent at 26.37 ± 3.42 %, 49.05 ± 4.48 %, and 24.57 ± 3.22 %, respectively.

There was however no significant ($P> 0.05$) main effects for trial, and no significant ($P> 0.05$) time*trial interactions for any of the accelerometry measures.

- COMPARISON OF ALL MODALITIES

The GLM did not identify any significant ($P> 0.05$) main effects for modality. The GLM did however identify a significant ($P= 0.05$, $\eta^2 = 0.27$) modalities*trial interaction for the PL_{ML} data, with significantly higher values being recorded in the third trial of the CONT (28.33 ± 6.52 a.u/km) condition when compared to the INT condition (24.60 ± 3.18 a.u/km). The 95% CI for this difference was 1.15 to 7.22 a.u/km.

As identified in table 6.4, a significant modalities*time interaction was identified for the PL_{ML} ($P=0.02$, $\eta^2=0.31$), PL_V ($P=0.05$, $\eta^2=0.29$), $PL_{AP\%}$ ($P=0.01$, $\eta^2=0.38$), and $PL_{ML\%}$ ($P=0.04$, $\eta^2=0.26$) data.

There was however no significant ($P>0.05$) modalities*trial*time interactions for any of the accelerometry measures.

Table 6.4 Time course of changes (irrespective of trial) in the accelerometry measures for each of the three modalities.

		Bout 1	Bout 2	Bout 3	Bout 4	Bout 5	Bout 6
INT	PL _{total} (a.u/km)	103.17 ± 9.78	103.72 ± 8.97	106.34 ± 9.96 ^b	107.61 ± 9.96 ^{ab}	107.68 ± 10.03 ^{ab}	108.00 ± 10.58
	PL _{AP} (a.u/km)	25.19 ± 4.64	25.72 ± 4.58	26.81 ± 5.02	27.39 ± 5.46 ^a	28.29 ± 5.42 ^{ab}	28.76 ± 5.39 ^{ab}
	PL _V (a.u/km)	52.52 ± 4.87	52.53 ± 4.86	53.78 ± 5.38 ^b	54.28 ± 5.18 ^{ab}	53.77 ± 6.10	53.37 ± 5.91
	PL _{ML} (a.u/km)	25.27 ± 4.28	25.46 ± 4.00	25.75 ± 4.28	25.94 ± 3.77	25.63 ± 3.51	25.87 ± 3.71 [*]
	PL _{AP} % (%)	24.37 ± 3.55	24.90 ± 3.47	25.14 ± 3.60	25.37 ± 3.81	26.22 ± 3.93 ^{acd}	26.57 ± 3.80 ^{acd}
	PL _{ML} % (%)	24.29 ± 2.14	24.45 ± 2.23	24.11 ± 2.24	24.04 ± 1.91	23.77 ± 1.96	23.91 ± 1.86
	PL _V % (%)	51.26 ± 4.53	50.80 ± 4.50	50.75 ± 4.70	50.59 ± 4.35	50.01 ± 4.56 ^a	49.52 ± 4.07 ^a
RS	PL _{total} (a.u/km)	102.69 ± 10.38	101.19 ± 11.39	103.16 ± 12.07	101.34 ± 15.19	103.84 ± 12.25	105.43 ± 12.03
	PL _{AP} (a.u/km)	27.76 ± 4.32	27.80 ± 4.56	28.57 ± 4.52	27.97 ± 4.78	28.90 ± 4.78 ^d	29.18 ± 4.21 ^{abd}
	PL _V (a.u/km)	49.84 ± 5.68 [#]	48.42 ± 5.66 [#]	48.85 ± 5.87 [#]	48.27 ± 6.11 [#]	49.30 ± 5.56 [#]	50.02 ± 5.88
	PL _{ML} (a.u/km)	26.30 ± 3.53	26.19 ± 4.09	26.99 ± 4.42	27.03 ± 5.22	26.92 ± 4.49	27.46 ± 4.61
	PL _{AP} % (%)	27.32 ± 4.33 [#]	27.65 ± 4.06 [#]	27.90 ± 3.76	27.92 ± 3.54	28.00 ± 3.94	27.94 ± 3.60
	PL _{ML} % (%)	25.67 ± 2.78 [#]	25.92 ± 3.08 [#]	26.21 ± 3.38 [#]	26.73 ± 3.38 [#]	25.94 ± 3.13 [#]	26.07 ± 3.35 [#]
	PL _V % (%)	48.68 ± 4.59	48.05 ± 4.78	47.57 ± 4.85	48.15 ± 5.87	47.73 ± 4.99	47.66 ± 4.89
CONT	PL _{total} (a.u/km)	104.39 ± 10.47	108.15 ± 14.14	113.37 ± 15.51 ^{ab}	117.08 ± 18.51 ^a	117.59 ± 21.31 ^{ab}	121.59 ± 21.98 ^{ab}
	PL _{AP} (a.u/km)	27.37 ± 4.11	28.94 ± 5.32 ^a	30.17 ± 5.06 ^{ab}	30.48 ± 5.29 ^a	30.16 ± 5.92	31.96 ± 7.44 ^{ab}
	PL _V (a.u/km)	51.29 ± 6.70	52.40 ± 7.35	55.07 ± 8.71 ^{ab}	57.77 ± 11.68 ^{ab}	57.59 ± 12.91	59.08 ± 11.93 ^{ab}
	PL _{ML} (a.u/km)	25.37 ± 3.71	26.48 ± 5.22	27.59 ± 5.44 ^{ab}	28.31 ± 5.49 ^{ab}	29.28 ± 5.99 ^{ab}	29.91 ± 6.13 ^{abcd}
	PL _{AP} % (%)	26.30 ± 3.01	26.77 ± 3.19	26.78 ± 3.38	26.23 ± 3.59	25.84 ± 3.66	26.32 ± 3.69
	PL _{ML} % (%)	24.43 ± 3.11	24.50 ± 3.14	24.36 ± 3.05	24.31 ± 3.36	25.04 ± 3.31	24.79 ± 3.38
	PL _V % (%)	49.27 ± 3.82	48.73 ± 4.18	48.86 ± 4.39	49.45 ± 4.92	49.12 ± 4.86	48.89 ± 4.71

^{abcdef} Denote significant differences from bout 1, bout 2, bout 3, bout 4, bout 5, and bout 6 respectively. ^{*} Denotes a significant difference with the CONT modality. [#] Denotes a significant difference with the INT modality.

6.3.3 Fast eccentric KF PT response

- INT

A significant ($P= 0.01$, $\eta^2 = 0.52$) main effect for time was identified with significantly higher pre-trial values (151.37 ± 31.03 Nm) when compared to post-trial (138.33 ± 29.51 Nm). The 95% CI for this difference was 3.61 to 22.49 Nm.

Significant ($P= 0.02$, $\eta^2 = 0.35$) main effects for trial were also observed, with significantly higher values in the first trial (154.17 ± 35.25 Nm) when compared to the second (141.27 ± 28.51 Nm) and third trial (139.12 ± 26.23 Nm). The 95% CI for these differences were 2.51 to 27.59 Nm and 0.63 to 26.43 Nm, respectively.

There was however no significant ($P= 0.49$) trial*time interaction.

- RS

The GLM identified a significant ($P= 0.01$, $\eta^2 = 0.51$) main effect for time, with significantly lower values being recorded post-trial (144.87 ± 26.78 Nm) when compared to pre-trial (135.89 ± 25.40 Nm). The 95% CI for this difference was 2.36 to 15.61 Nm.

There was however no significant ($P= 0.10$) main effects for trial, and no significant ($P= 0.27$) trial*time interaction.

- CONT

A significant ($P= 0.001$, $\eta^2 = 0.73$) main effect for time was identified, with significantly higher values being recorded pre-trial (142.45 ± 35.35 Nm) when compared to post-trial (123.46 ± 24.32 Nm). The 95% CI for this difference was 10.29 to 27.69 Nm.

The GLM also identified a significant ($P= 0.02$, $\eta^2 = 0.37$) main effect for trial with significantly higher values in the first trial (141.05 ± 32.90 Nm) when compared to both the second (127.93 ± 33.60 Nm) and third trial (129.89 ± 27.90 Nm). The 95% CI for these differences were 1.42 to 20.91 Nm and 2.16 to 24.08 Nm, respectively.

As identified in figure 6.5, the GLM also identified a significant ($P= 0.01$, $\eta^2 = 0.53$) trial*time interaction, with significantly higher values being recorded pre-trial 1 (157.82 ± 33.79 Nm) when compared to both pre-trial 2 (138.60 ± 39.83 Nm) and 3 (130.94 ± 29.55 Nm). The 95% CI for these differences was 3.64 to 34.80 Nm and 4.99 to 48.75 Nm.

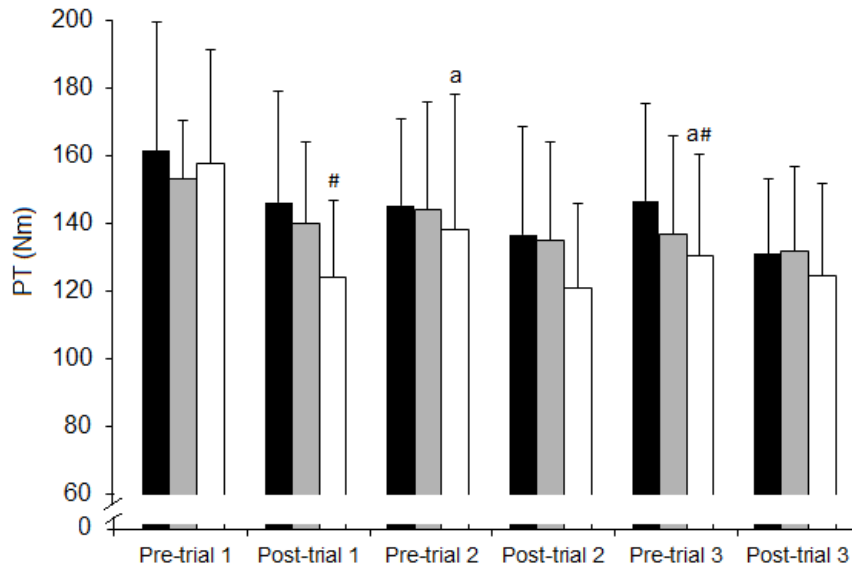


Figure 6.5 Time history of changes in fast eccentric KF PT recorded across the three experimental trials (CONT [□], RS [■], and INT [■]). # denotes a significant difference with the INT modality. ^a denotes a significant difference with trial 1.

- COMPARISON OF ALL MODALITIES

The GLM did not identify any significant ($P=0.07$) main effects for modality and there were no significant Modality*Time ($P= 0.15$) or Modality*Trial ($P= 0.94$) interactions.

As identified in figure 6.5, there was a significant ($P= 0.04$, $\eta^2 = 0.24$) modalities*trial*time interaction, with post-trial 1 (124.28 ± 22.77 Nm) and pre-trial 3 (130.94 ± 29.55 Nm) being significantly lower in the CONT modality when compared to the INT modality (Post1= 146.59 ± 32.60 Nm; Pre3= 153.50 ± 17.06 Nm). The 95% CI for these differences were -42.29 to -2.33 Nm and -29.45 to -2.40 Nm, respectively.

6.3.4 Slow eccentric KF PT response

- INT

As identified in figure 6.6, a significant ($P= 0.05$, $\eta^2 = 0.37$) main effect for time was identified, with significantly higher pre-trial values (142.33 ± 41.26 Nm) when compared to post-trial (134.23 ± 28.87 Nm). The 95% CI for this difference was 0.17 to 16.03 Nm.

Significant ($P= 0.02$, $\eta^2 = 0.35$) main effects for trial were also observed, with significantly higher values in the first trial (145.61 ± 42.86 Nm) when compared to the third trial (131.10 ± 35.38 Nm). The 95% CI for this difference was 0.82 to 30.01 Nm.

There was however no significant ($P= 0.44$) trial*time interaction.

- RS

As identified in figure 6.6, a significant ($P= 0.01$, $\eta^2 = 0.53$) main effect for time was identified, with significantly higher pre-trial values (140.93 ± 29.80 Nm) when compared to post-trial (128.71 ± 22.41 Nm). The 95% CI for this difference was 3.54 to 20.91 Nm.

There was however no significant ($P= 0.09$) main effects for trial, and no significant ($P= 0.79$) trial*time interaction.

- CONT

As identified in figure 6.6, a significant ($P= 0.002$, $\eta^2 = 0.27$) main effect for time was identified, with significantly higher pre-trial values (143.48 ± 40.20 Nm) when compared to post-trial (126.84 ± 33.76 Nm). The 95% CI for this difference was 8.19 to 25.08 Nm.

There was however no significant ($P= 0.06$) main effects for trial, and no significant ($P= 0.14$) trial*time interaction.

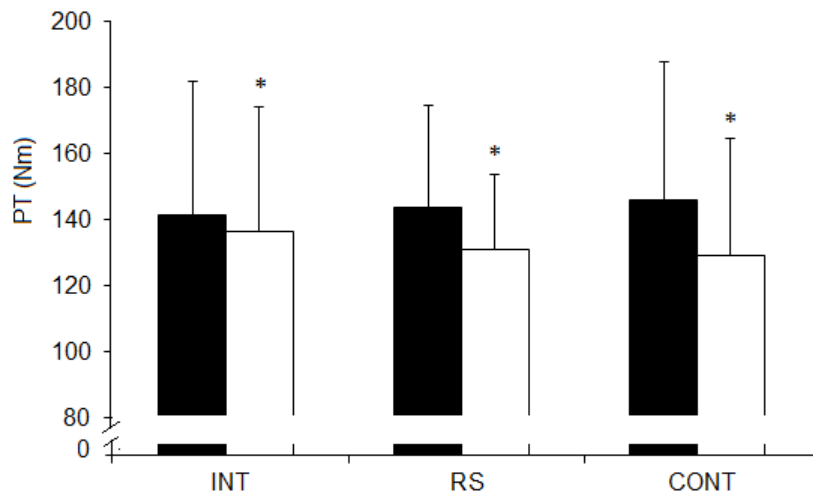


Figure 6.6 Pre- [■] and post-trial [□] measures of slow eccentric KF PT recorded across the three modalities. * denotes a significant difference with pre-trial.

- COMPARISON OF ALL MODALITIES

The GLM identified no significant ($P=0.95$) main effects for modality, and no significant modality*trial ($P= 0.71$), modality*time ($P= 0.21$), and no modality*trial*time ($P= 0.55$) interactions.

6.3.5 MS response

- INT

Figure 6.7 illustrates the time history of changes MS across the experimental trials. The GLM identified significantly ($P < 0.001$, $\eta^2 = 0.85$) higher values post-trial (51 ± 24 a.u) when compared to pre-trial (20 ± 19 a.u). The 95% CI for this difference was 21 to 41 a.u.

The GLM also identified a significant ($P = 0.01$, $\eta^2 = 0.42$) main effect for trial, with significantly higher perceptions of muscle soreness in the third trial (42 ± 25 a.u) when compared to the first trial (29 ± 29 a.u). The 95% CI for this difference was 0 to 26 a.u.

There was however no significant ($P = 0.72$) trial*time interaction.

- RS

The GLM identified significantly ($P = 0.001$, $\eta^2 = 0.71$) higher values post-trial (32 ± 22 a.u) when compared to pre-trial (14 ± 13 a.u). The 95% CI for this difference was 9 to 26 a.u.

There was however no significant ($P = 0.24$) main effect for trial, and no significant ($P = 0.72$) trial*time interaction.

- CONT

The GLM identified significantly ($P < 0.001$, $\eta^2 = 0.96$) higher values post-trial (70 ± 19 a.u) when compared to pre-trial (26 ± 24 a.u). The 95% CI for this difference was 36 to 50 a.u.

As identified in figure 6.7, the GLM also identified a significant ($P = 0.01$, $\eta^2 = 0.40$) main effect for trial, with significantly higher perceptions of muscle soreness in the second trial (54 ± 22 a.u) when compared to the first trial (40 ± 34 a.u). The 95% CI for this difference was 2 to 25 a.u.

As identified in figure 6.7, there was also a significant ($P = 0.03$, $\eta^2 = 0.32$) trial*time interaction, with significantly higher values being recorded pre-trial 2 (40 ± 18 a.u) when compared to pre-trial 1 (12 ± 16 a.u). The 95% CI for this difference was 9 to 47 a.u.

- COMPARISON OF ALL MODALITIES

The GLM identified a significant ($P < 0.001$, $\eta^2 = 0.60$) main effects for modality, with significantly higher values being observed in the CONT modality (48 ± 31 a.u) when compared to the RS modality (23 ± 20 a.u). The 95% CI for this difference was 8 to 42 a.u.

The GLM did not identify a significant Modality*Trial ($P= 0.10$) interaction; however, there was a significant Modalities*Time ($P< 0.001$, $\eta^2 = 0.60$) interaction. Post hoc pairwise comparisons identified significantly lower post-trial values in the RS modality (31 ± 22 a.u) when compared to both the INT (51 ± 24 a.u) and CONT modalities (70 ± 19 a.u). The 95% CI for these differences were -35 to -4 a.u and -58 to -18 a.u.

As identified in figure 6.7, a significant Modalities*Trial*Time interaction ($P= 0.01$, $\eta^2 = 0.33$) was also identified for the MS data. Post hoc pairwise comparisons also identified significantly higher MS values post-trial 1, pre-trial 2, post-trial 2, and post-trial 3 in the CONT modality (69 ± 16 ; 41 ± 18 a.u; 69 ± 16 a.u; and 69 ± 19 a.u) when compared to the RS (27.3 ± 19 a.u; 16 ± 10 a.u; 36 ± 20 a.u; and 33 ± 27 a.u). The 95% CI for these differences were 22 to 61 a.u, 12 to 37 a.u, 12 to 52 a.u, and 12 to 68 a.u, respectively. Furthermore, significantly higher values were recorded post-trial 1 and pre-trial 2 in the CONT modality when compared the INT (45 ± 29 a.u; 19 ± 13 a.u). The 95% CI for these differences were 1 to 46 a.u and 9 to 33 a.u, respectively. Significantly higher values were also observed post-trial 3 in the INT modality (56 ± 21 a.u) when compared to the RS (32.5 ± 27 a.u). The 95% CI for this difference was 6 to 41 a.u.

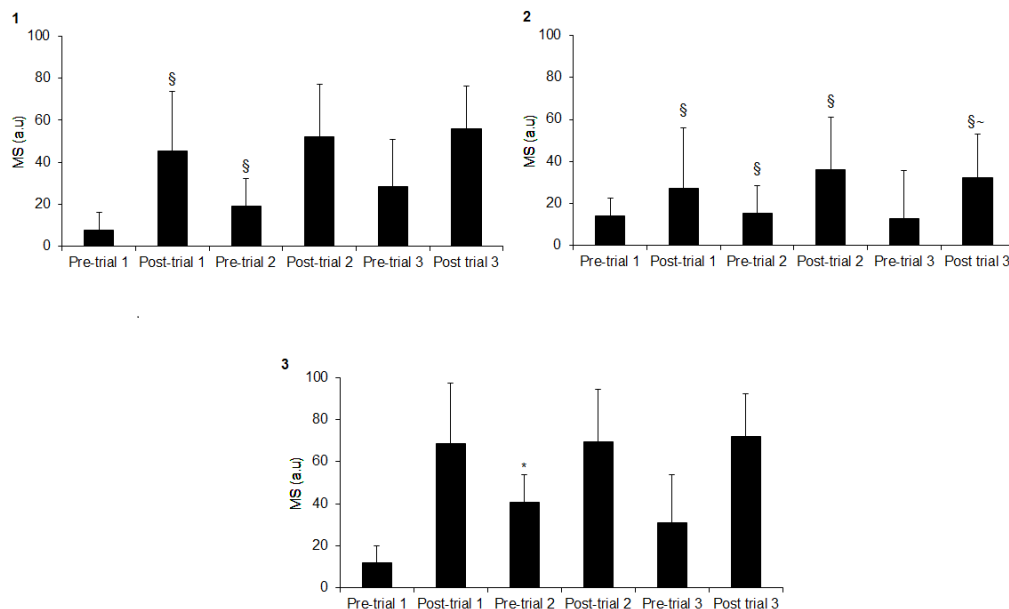


Figure 6.7 Time course of changes in the MS data across each trial for the three modalities (1= INT; 2= RS; 3= CONT). * denotes a significant difference from pre-trial 1. § denotes a significant difference with the CONT modality. ~ denotes a significant difference with the INT modality.

6.3.6 BF EMG response

- INT

The GLM identified significant ($P < 0.001$, $\eta^2 = 0.61$) main effects for time, with significantly higher EMG_{mean} values in the first three bouts ($T_1 = 108.28 \pm 22.94 \mu\text{V}$; $T_2 = 95.67 \pm 28.68 \mu\text{V}$; $T_3 = 99.92 \pm 30.02 \mu\text{V}$) when compared to the fifth bout ($77.8 \pm 32.83 \mu\text{V}$). The 95% CI for these differences were 2.01 to 58.92 μV , 0.06 to 35.65 μV , and 9.94 to 34.27 μV , respectively. Significantly higher EMG_{mean} values were also identified in the first and third bout when compared to the fourth bout ($79.3 \pm 26.36 \mu\text{V}$). The 95% CI for these differences were 6.42 to 51.62 μV and 0.25 to 41.05 μV , respectively. Significantly higher values were also observed during the first bout when compared to the final bout ($76.1 \pm 36.04 \mu\text{V}$). The 95% CI for this difference was 11.43 to 52.94 μV .

The GLM also identified no significant ($P = 0.59$) main effect for trial for EMG_{mean} data; however, as identified in figure 6.8, there was a significant ($P = 0.003$, $\eta^2 = 0.36$) trial*time interaction associated with EMG_{mean} data. Post hoc pairwise analysis identified significantly higher EMG_{mean} values in the final bout of the first trial ($99.97 \pm 39.81 \mu\text{V}$) when compared to the corresponding time point in the third trial ($52.18 \pm 17 \mu\text{V}$). The 95% CI for this difference was 7.61 to 87.97 μV . Similarly, significantly higher EMG_{mean} values were recorded in the first bout ($126.36 \pm 15.57 \mu\text{V}$) of the third trial when compared to the corresponding measurement point in the first trial ($98.20 \pm 23.49 \mu\text{V}$). The 95% CI for this difference was 5.35 to 52.52 μV .

- RS

The GLM identified no significant main effects for trial ($P = 0.16$) or time ($P = 0.68$); however, as identified in figure 6.8 there was a significant ($P = 0.01$, $\eta^2 = 0.33$) trial*time interaction, with significantly higher values being identified in the final 3 bouts of the first trial ($T_4 = 63.23 \pm 19.45 \mu\text{V}$; $T_5 = 76.24 \pm 23.19 \mu\text{V}$; $69.31 \pm 20.91 \mu\text{V}$) when compared to the corresponding bouts in the third trial ($T_4 = 43.22 \pm 9.16 \mu\text{V}$; $T_5 = 46.11 \pm 14.43 \mu\text{V}$; $42.77 \pm 12.88 \mu\text{V}$). The 95% CI for these differences were 2.27 to 37.76 μV , 3.35 to 56.92 μV , and 5.85 to 47.88 μV , respectively.

- CONT

The GLM identified a significant ($P= 0.003$, $\eta^2 = 0.63$) main effect for trial, with significantly higher values being recorded in the second trial ($54.10 \pm \mu\text{V}$) when compared to both the first ($37.63 \pm 20.66 \mu\text{V}$) and third trial ($33.95 \pm 16.51 \mu\text{V}$). There was however no significant ($P= 0.29$) main effect for time, and no significant ($P= 0.36$) trial*time interaction.

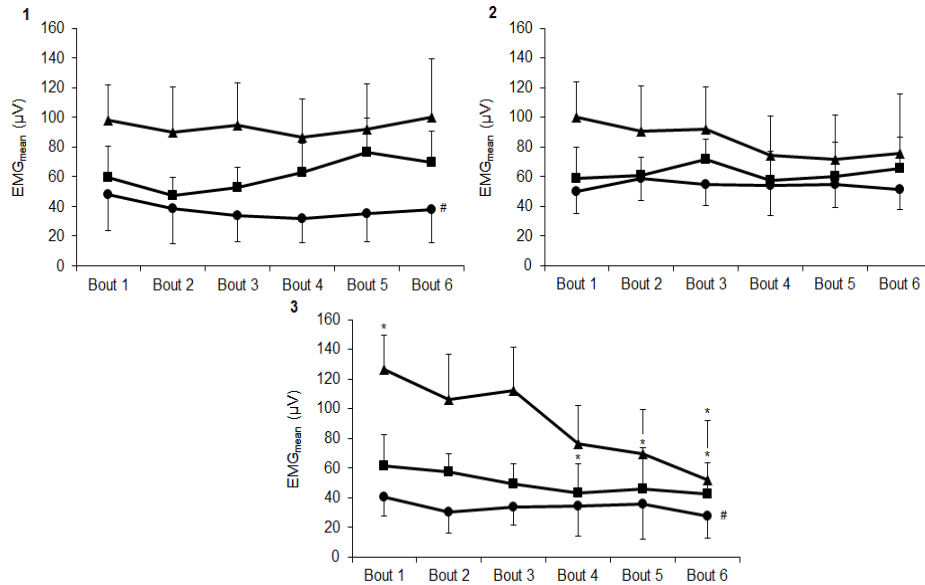


Figure 6.8 Time course of changes in the EMG_{mean} data recorded during each trial (1, 2, and 3) for the three modalities (■ = RS; ▲ = INT; ● = CONT). # denotes a significant difference with the second trial. *denotes a significant difference with the first trial.

6.4 DISCUSSION

Similar to the data reported in studies 1 and 2 (Chapters 4 and 5 respectively), the cumulative fatigue effect associated with the RPE and physiological data recorded in the INT trials was comparable to match-play observations (Mohr et al., 2003; Stølen et al., 2005; Krstrup et al., 2006b; Mohr et al., 2012; Scott et al., 2013). With the exception of the $\dot{V}\text{O}_2$ data recorded in the second trial, the RS modality elicited a similar physiological and perceptual response when compared to the INT modality. The RS protocol utilised in the current study may, therefore, offer a time efficient method of eliciting a physiological response specific to soccer match-play. A trend for a consistently higher physiological and RPE data was also identified in the CONT trials when compared to the other two modalities. This data suggests that this

mode of exercise could be utilised pre-season to elicit an overload training stimulus to aid the physiological conditioning of soccer players (Stone and Kilding, 2009).

The physiological and RPE data was highest in the first CONT trial and lowest in the second. Lambert et al., (2005) suggested that during exercise, sensations of exertion are consciously interpreted by drawing upon mental representations and beliefs that have been constructed through similar previous occurrences. The lower RPE and physiological response observed in the second and third trials may therefore be related to the participant's knowledge that they had successfully completed the first trial. Although the participants were familiarised prior to testing, the elevated physiological and RPE response in the first CONT trial may also be a result of the unaccustomed nature of this type of activity. Soccer-specific training is now typically characterised by time efficient activities such as small sided games (Morgans et al., 2014), with less emphasis being placed on long duration bouts of continuous running. Similarly, the instruction provided to the participants prior to the first CONT trial may have also resulted in the players adopting an 'all-out' pacing strategy instead of the innate 'slow-positive' strategy typically adopted during a game (Waldron and Highton, 2014).

Significant differences were observed in the RPE, $\dot{V}O_2$, and $\dot{V}O_{2peak}$ data recorded in the successive CONT trials when compared to the INT and RS. These differences appear to be related to the higher average running velocity when compared to the INT modality, and the increased volume of activity when compared to the RS modality. The observed differences may also be indicative of the beneficial effects associated with punctuating periods of activity with periods of active and/or passive recovery. The lack of significant differences in the latter stages of the second and third trials is potentially due to a combination of the lower running velocities observed towards the end of the CONT trials, and as discussed previously potentially a lower stress response in the second and third CONT trials.

The current data suggests that 48 h recovery is sufficient to prevent detrimental fatigue induced alterations in the physiological and RPE responses associated with successive bouts of CONT, RS, and INT exercise. The finding of no change in the physiological response across successive trials is as expected. For example, although the current physiological variables may briefly remain elevated post-trial, these measures will be fully recovered within minutes following the completion of each trial. As previously discussed in study 1 (chapter 4), the net rate of blood lactate clearance associated with semi-professional soccer players during passive rest has been shown to be $\sim 0.1 \text{ mmol} \cdot \text{L}^{-1} \cdot \text{min}^{-1}$ (Krustrup et al.,

2006b), as such, the current BL_a concentrations would therefore return to baseline within ~17, 36, and 47 mins following the completion of the RS, INT and CONT trials respectively.

All accelerometry measures recorded in the INT modality were comparable with those observed during soccer match-play (Barron et al., 2014). With the exception of PL_{ML} and PL_{ML}%, a significant cumulative fatigue response was observed for all accelerometry measures across the INT trials. However, in support of study 2 (Chapter 5), there was no residual fatigue response observed across the successive INT trials. A similar residual fatigue response was also identified for the accelerometry data recorded across the CONT and RS trials. A cumulative fatigue response was identified for the PL_{AP} data in the RS trials, and for PL_{total}, PL_V, PL_{AP}, and PL_{ML} during the CONT trials. The observed increases in the PL_{AP} data identified towards the latter stages of the RS trials is indicative of a fatigue induced alteration in upper body positioning, specifically increased forwards and backwards lean (Cormack et al., 2013a). The lack of compensatory changes in the uni-axial measures recorded in the CONT trials suggests an alteration in movement efficiency rather than a change in technique. These data are indicative of the unfamiliar nature of the continuous running. In further support of an alteration in movement efficiency, it was also identified that although the average running velocities reduced towards the end of each CONT trial, all absolute accelerometry values continued to increase.

The current accelerometry data appears to be specific to each velocity profile with no commonality observed between modalities. An interesting observation of the current study was that there were no significant differences in the PL_{total} data recorded across the different modalities. The PL_{total} data therefore does not appear to be sensitive enough to detect changes in running technique and/or efficiency between different modalities. Tri-axial PlayerLoad™ should therefore not be the only PlayerLoad™ metric considered when assessing the mechanical demand associated with different bouts of activity.

Irrespective of trial, significantly lower PL_V and higher PL_{ML}% and PL_{AP}% data were identified in the RS modality when compared to the INT. The observed differences appear to be a result of an increased laterality in running technique during the RS modality when compared to the INT. The current observations are indicative of the differences in acceleration mechanics adopted between the two conditions. For example, all HI efforts in the RS modality are completed from a stationary position, whereas during the INT modality some HI efforts are initiated from LI running velocities. Furthermore, the maximal velocities of the HI efforts

associated with the RS modality are greater than some of the HI efforts completed in the INT modality. As such, the participants typically have to accelerate more explosively and for longer during the RS modality when compared to the INT.

The current data also identified significantly higher PL_{ML} data in the third CONT trial when compared to the INT. This observation is supported by previous research that identified that long and/or intensive running induces mechanical alterations within the musculoskeletal system, resulting in degradations in postural regulation (Paillard, 2012; Steib et al., 2013). Furthermore, Le bris et al., (2006) identified that with fatigue athletes will increase medial-lateral displacement. The observed increases in PL_{ML} data in the third CONT trial occur when the KF PT is most impaired. It has previously been suggested that reductions in muscular strength may result in a compromised capability for joint stabilisation thus potentially resulting in increased medial-lateral displacement and an increased risk of muscular and ligamentous injuries (Rahnama et al., 2003). It should be acknowledged that the observed differences in the PL_{ML} data is specific to the location of the unit, and may not refer to alterations in lower limb kinematics (Barrett et al., 2014).

Irrespective of trial, eccentric KF PT recorded at both slow ($60 \text{ deg}\cdot\text{s}^{-1}$) and fast speeds ($300 \text{ deg}\cdot\text{s}^{-1}$) was significantly reduced following the completion of the RS, CONT, and INT trials. The observed pre- to post-trial reductions in KF PT recorded in the INT modality is lower than that associated with previous literature (Greig et al., 2006; Small et al., 2010; Cohen et al., 2015; Cortella et al., 2015), but is still in support of epidemiological observations of increased KF injury risk during the latter stages of match-play (Ekstrand et al., 2011). The first CONT, RS, and INT trials reduced fast speed PT by 21, 9, and 9% respectively. As such, significantly lower fast speed PT values were recorded post-trial 1 in the CONT modality when compared to the INT. However, due to lower pre-trial 1 values recorded in the RS modality, the post-trial 1 data in the CONT and RS trials was not significantly different. The large reductions in eccentric KF PT observed during the CONT modality may be indicative of muscular damage (Cheung et al., 2003) and failure of the myofibrillar apparatus (Oliveira et al., 2009) due to the unaccustomed nature and high frequency of eccentric contractions performed during the CONT trials. Practitioners should therefore be aware that prolonged aerobic sessions elicit large torque decreases under eccentric conditions, with implications for subsequent performance and injury risk (Oliveira et al., 2009).

The RS and INT velocity profiles emphasise a large number of HI eccentric contractions, associated with muscle damage and subsequent reductions in peak torque (Eston et al., 2003; Amann, 2011). The increased volume of activity associated with the INT modality appears to have no additional effect on the magnitude of change in fast speed PT data recorded in the first INT and RS trial. Previous literature has identified that the completion of a single set of Nordic hamstring exercises (5 repetitions) is sufficient to significantly impair KF PT (Marshall et al., *In Press*). It has also been identified that significant reductions in KE MVC's can occur following the completion of as few as two maximal 30 m sprints (Goodall et al., 2015). The large number of HI efforts in the first bouts of the INT and RS modalities may therefore have been sufficient to significantly reduce KF PT, with only small further reductions occurring across the remainder of the trials. In further support of the suggestion of early reductions in KF PT occurring in the current RS and INT trials, it has previously been identified that the greatest reductions in in BF muscle activity and eccentric KF PT occur during the first 45 mins of previous SSEP's (Rahnama et al., 2006; Greig et al., 2008; Small et al., 2010; Marshall et al., 2014).

Although the INT and RS modality elicited the same magnitude of fatigue across the first trial, there were differences in the rate of post-trial mechanical recovery between the two modalities. Fast speed PT was not significantly different in the second RS trial when compared to the first; however, significantly lower fast speed KF PT values were recorded in the second INT trial. Reductions in a player's capacity to generate KF PT at fast speeds may result in an increased susceptibility to injury during the completion of ballistic actions, such as accelerating and decelerating from sprinting (Greig, 2008). The current data therefore supports the notion of increased injury risk (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015), and observed reductions in physical activity during periods of fixture congestion (Odetoyinbo et al., 2007; Carling et al., 2012).

Significantly lower values were also identified in the second CONT trial when compared to the first. The observed differences in the rate of post-trial mechanical recovery between the different modalities appear to be related to the volume of activity performed in the INT and CONT trials. The high volumes of activity may elicit an elevated peripheral fatigue response during the interspersing recovery period (Rampinini et al., 2011; Nédélec et al., 2012). It has been suggested that reductions in KF PT observed during soccer match-play may occur as a result of reductions in central motor output in an attempt to offset the occurrence of peripheral fatigue (Rampinini et al., 2011; Marshall et al., 2014; Timmins et al., 2014;

Goodall et al., 2015). It also seems logical that a similar response could occur during the interspersing recovery period, thus resulting in lower fast speed PT values being recorded at the beginning of the second INT and CONT trials. It is also feasible that the fatigue response associated with the RS modality is predominantly central in origin with only small influences of peripheral fatigue. In support of this, previous literature has identified that central fatigue recovers at a far greater rate than peripheral and biochemical markers (Minet and Duffield 2014). In further support of the notion that the high volumes of activity impairing mechanical recovery, significantly lower KF PT values were also recorded in the third trial of the INT and CONT modalities when compared to the first.

Significantly lower slow speed PT values were also recorded in the third INT trial when compared to the first trial. It is possible that the high frequency of HI running, accelerations, and decelerations during the completion of the INT trials could have resulted in muscle damage, particularly with the repeatedly recruited type II muscle fibres, which are more susceptible to muscle damage than type I fibres (Eston et al., 2003). The rates of fatigue associated with different fibre types may help to explain the current data, whereby fast speed PT is significantly reduced as early as the second trial, whereas the slow speed PT is not significantly impaired until the final trial. The observed reductions in fast and slow speed PT may also be due to a decrease in the number of fibres that can be recruited to generate force (Rahnama et al., 2003). There were no differences in the fatigue response identified for the slow speed PT data recorded across the three CONT and RS trials. The significantly lower slow speed PT values observed in the third INT trial must therefore be related to high frequency of speed changes and/or the completion of some LI periods of activity within the INT protocol

Significantly lower fast speed PT values were also recorded pre-trial three in the CONT modality when compared to the INT. The observed difference at the beginning of the third trial may be related to the lower average running velocity, the interspersing periods of recovery, and the more familiar nature of the INT modality when compared to the CONT. It was also identified that there were considerable increases in the fast speed PT data recorded pre-trial 3 in the INT and CONT trials when compared to the values recorded post-trial two. The observed increase in fast speed PT at the beginning of the third CONT and INT trials appears to be indicative of a protective mechanism associated with increased motor unit recruitment in an attempt to assist with the completion of the high volume of activity. In the same way that reductions in central motor output can occur to offset the occurrence of

peripheral fatigue during exercise (Rampinini et al., 2011; Marshall et al., 2014; Goodall et al., 2015), central motor output could also be increased to elicit an increased neuromuscular effort in an attempt to compensate for the existence of residual physical fatigue (Eston et al., 2003; Rahnema et al., 2006). The current PT data suggests that the residual fatigue response is most greatly influenced by the volume of activity performed across the successive trials. These data also identify the potentially beneficial effects of punctuating periods of activity with periods of passive recovery.

In support of the KF PT data, significantly higher MS values were elicited in the final INT trial when compared to the first. The observed increase in MS in the third INT trial may therefore support previous observations of reduced activity during periods of fixture congestion (Odetoyinbo et al., 2007; Carling et al., 2012). Significantly higher MS values were also recorded in the second CONT trial when compared to the first. The elevated MS values in the second CONT trial appear to be a result of significantly higher MS values identified pre-trial 2 when compared the pre-trial 1. There was however no significant differences in any of the post-trial measures, thus suggesting that the greatest pre- to post-trial difference occurred in the first CONT trial, with the lowest in the second trial. These data therefore support the response observed with the physiological and RPE data. In further support of the KF PT data, there was no significant difference in the MS response recorded across the successive RS trials. The RS modality consistently elicited the lowest cumulative and residual MS response, with the CONT eliciting the highest.

As is evident from the current data, the observed fatigue response is similar between the MS and the muscle strength data (Rampinini et al., 2011). Similar mechanisms must therefore be associated with the observed changes in these measures; with muscle damage and/or muscle inflammation are the most likely candidates to explain this relationship (Cheung et al., 2003). Measures of muscle soreness could therefore potentially be utilised to infer alterations in muscular strength without the use of expensive and time consuming clinical measurement tools; however, this suggestion warrants further investigation. Overall the MS response observed across the successive INT trials appears to be more greatly influenced by the volume of activity performed, rather than the number of HI efforts completed.

In support of previous observations (Timmins et al., 2014), the observed pre- to post-trial changes in the MS and KF PT data recorded in the INT modality appears to mirror the temporal pattern in muscular response to the exercise protocol, with BF EMG_{mean} at 25

km·hr⁻¹ decreasing as a function of exercise duration ($T_{0-15} = 108.28 \pm 22.94 \mu\text{V}$; $T_{75-90} = 76.10 \pm 36.04 \mu\text{V}$). The observed reductions in BF muscle activity support previous research that has assessed changes in muscle activity during the completion of soccer-specific activity (Rahnama et al., 2006; Rampinini et al., 2011; Marshall et al., 2014), and epidemiological observations of increased KF injury risk during the latter stages of match-play (Ekstrand et al., 2011).

Significantly higher BF muscle activity was observed at the beginning of the third INT trial when compared to the first trial. Due to the standardised nature of the INT protocol, the current data identifies an increased neural recruitment at the beginning of the third trial to achieve the same workload (Eston et al., 2003; Rahnama et al., 2006; Greig et al., 2008). The increased BF muscle activity at the beginning of the third INT trial occurs concurrently with the observed increase in fast speed PT recorded pre-trial three in the INT modality when compared to the values recorded post-trial two. The increased neural recruitment observed at the beginning of the third INT trial does not appear to occur in the third RS trial. This observation further supports that the increase in muscular activity at the beginning of the third INT trial occurs in an anticipatory manner to help cope with the high volume of activity (Eston et al., 2003; Rahnama et al., 2006).

Following the increase in muscle activity observed at the beginning of the third trial there is a considerable reduction in the second half, with significantly lower BF muscle activity being recorded in the final measurement point of the third trial when compared to the first. The RS trial also appears to elicit a similar fatigue effect in the third trial. The current EMG_{mean} data therefore appears to suggest that the BF is able to perform a finite number of HI efforts over a 5 day period before reductions in muscular activity occur. Goodall et al., (2015) suggested the completion of repeated HI efforts heavily taxes short-term energy pathways and relies on the recruitment of high threshold motor units. Reductions in central motor output therefore inevitably occur to offset the residual fatigue response elicited from the completion of successive bouts of repeated HI activity.

In support of previous observations (Oliviera et al., 2009), the EMG_{mean} data recorded in the CONT modality does not appear to reduce as a function of exercise duration. These data therefore further suggest that the residual fatigue responses observed with the MS and KF PT data during the completion of the CONT trials is most greatly influenced by peripheral fatigue mechanisms. Significantly higher EMG_{mean} values were recorded in the second CONT

trial when compared to the first. This increase in muscular activity appears to be a result of increased central output indicative of the participant's lower perceptions of effort in the second CONT trial (Waldron and Highton, 2014). The CONT data therefore supports the notion that central motor output can be increased or reduced in an attempt to regulate exercise performance, and these alterations can occur in an anticipatory or reactive manner (Marshall et al., 2014; Waldron and Highton, 2014).

The concurrent alterations in MS, KF PT and BF activity in the third INT trial supports previous observations of increased injury risk during periods of fixture congestion (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015). It has previously been observed that team sport players will alter their activity profiles to preserve their HI running capacity (Smith et al., *In Press*), and that these alterations may be more pronounced during periods of short-term fixture congestion (Folgado et al., 2015). However, it is difficult to identify if these reductions in performance are indicative of the self-paced nature of match-play, or if they are a result of decreased physical capacity. The current study identified altered physical capacity during a period of short-term fixture congestion, thus supporting previous observations of reduced physical performance during periods of fixture congestion (Carling et al., 2010; Odetoyinbo et al., 2007; Rollo et al., 2014).

Although the need to standardise the activity profile within and between games was fundamental to the current study, the use of a treadmill protocol negates the inclusion of soccer-specific utility movements which can further induce muscle damage (Small et al., 2010; Cohen et al., 2015; Cortella et al., 2015) and influence the time to recovery. As such, the current data may be considered to provide a conservative mechanical response when compared to soccer match-play, thus further reiterating the implications of the current study. Future research should attempt to investigate potential methods to either reduce the mechanical load elicited from soccer-match play, or attempt to artificially speed up the time course of mechanical recovery between successive bouts of match-play.

6.5 CONCLUSION

The current study identified no residual fatigue effect in the RPE, accelerometry, and physiological data recorded across the three successive bouts of soccer-specific exercise. This response was also observed for both the CONT and RS modalities. The RS modality consistently elicited the lowest physiological and RPE response, with the CONT modality

eliciting the highest. The RS modality elicited a physiological and RPE response most similar to the INT protocol.

The mechanical response associated with the INT modality was characterised by insufficient recovery of fast speed eccentric KF PT with 48 h recovery, and further detriments in MS, BF muscular activity, and both slow and fast speed eccentric KF PT in the third trial. A similar yet more marked cumulative and residual fatigue response was observed for the MS and fast speed PT data during the CONT modality. The current data therefore suggests that the cumulative and residual fatigue effect observed for the fast speed PT and MS data is most greatly influence by the volume of activity performed across the successive trials. In relation to the BF muscle activity, both the RS and INT modality elicited reductions towards the end of the third trial, thus suggesting that the BF muscle activity is most greatly influenced by the number of HI efforts performed across the three trials.

The interaction of muscular response to soccer-specific activity, the subsequent reduction in muscular strength, and the perception of muscular soreness suggests a biomechanical and muscular emphasis with residual fatigue. The current data therefore supports previous observations of reduced physical performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) and increased injury risk (Dupont et al., 2010; Benggston et al., 2013; Dellal et al., 2015) during periods of fixture congestion. The current data has implications for the practitioner in relation to the micro management and design of training and competition schedules. This is particularly pertinent for youth soccer, where teams are often required to play with less than 48 h recovery between trials (Arruda et al., 2015). The current study also further reiterates the importance of ensuring KF strength is well developed and resistant to fatigue during periods of short-term fixture congestion.

CHAPTER SEVEN

STUDY FOUR

THE INFLUENCE OF PLAYER INTERCHANGE ON THE PHYSICAL RESPONSE TO A SOCCER-SPECIFIC SIMULATION

7.1 INTRODUCTION

Study 3 (Chapter 6) identified that the residual fatigue response associated with periods of short-term fixture congestion was most greatly influenced by the volume of activity performed. The data presented in study 3 also appears to suggest that the rate of post-trial mechanical recovery could potentially be enhanced by the punctuating activity with periods of passive recovery. It may therefore be possible to reduce injury risk and aid successive performance by reducing the volume of activity performed during a match. Study 4 has therefore been designed to assess the effect of a contemporary rule change (interchange rule) intervention on reducing the physical fatigue response (both cumulative and residual) associated with the completion of a SSEP.

The current rules in soccer permit the use of three substitutions during the completion of a competitive match, with these substitutions often being made towards the latter stages of the second half (Bradley et al., 2014). It has been suggested that substitutions are completed to either replace fatigued players (Reilly et al., 2008) or as a method of altering tactics towards the end of a match (Siegle and Lames, 2012). As a result of both the timing and the limited number of substitutions which are able to be used within soccer, the majority of players will be required to play for the full duration of a match. Coupled with the high frequency of games (Nédélec et al., 2013) and often short recovery periods associated with modern soccer (Dupont et al., 2010; Rollo et al., 2014; Carling et al., 2015; Dellal et al., 2015), players are regularly subjected to a high physical demand and a subsequent risk of injury (Dupont et al., 2010; Dellal et al., 2015).

A similar cumulative fatigue response and temporal pattern for running related injuries has been observed during Rugby Union match-play, with an increased risk of injury being identified during the latter stages of play (Fuller et al., 2007). Rugby union also restricts the number of permanent substitutions that can be used during a match. In contrast, injury incidence in Rugby League peaks during the middle stages of match-play (Seward et al., 1993; Gabbett, 2003). The velocity profiles associated with Rugby League are similar to both soccer and Rugby union, but teams are permitted to make 12 interchange substitutions during the course of a match. Orchard et al., (2012) identified that regular interchanges reduced the incidence of KF strain injuries in ARF players. This interchange rule may provide a protective effect by allowing players to leave the field of play and potentially recover, or by simply reducing the volume of activity performed (Orchard et al., 2012). The use of

substitutions and inter-changes in intermittent team sports might therefore offer potential implications for injury risk.

In 2006 FIFA approved that a player would be dismissed from the field of play if they were to make contact with an opposition's head with their elbow. Reductions in these type of injuries have been identified following the implementation of the aforementioned rule change (Tscholl et al., 2007; Junge and Dvořák, 2015), thus supporting that rule changes have potential to reduce injury incidence in soccer. Given that KF strains are the most common injuries in intermittent team sports (Orchard et al., 2012), potential rule changes may be designed to try and reduce non-contact injury incidence. Therefore, the aim of the current study was to assess the influence of player interchange on the physical response and the time course of recovery associated with the completion of a SSEP. The current study will replicate the majority of measures from study 3 (Chapters 6) with additional rigour in the some mechanical and perceptual measures.

7.2 METHOD

7.2.1 Participants

Thirteen male semi-professional soccer players (mean \pm SD: age 23.2 ± 4.6 yrs, height 181.4 ± 3.8 cm, body mass 81.0 ± 7.8 kg) volunteered to complete this study during the English competitive soccer season. Participant's eligibility was determined from the inclusion and exclusion criteria described in Chapter 3.1. Preliminary anthropometric and health screening procedures were also completed as described in Chapter 3.3. The study was approved by the University Research Ethics Committee and conformed to the declaration of Helsinki. Written informed consent was obtained for all participants prior to the commencement of data collection.

7.2.2 Experimental design

Participants attended the laboratory on five occasions to complete a 30min familiarisation trial, two experimental trials, and two follow up assessment. All trials were completed on a programmable motorised treadmill (Chapter 3.5). The familiarisation trial comprised 2 x 15 min bouts of the SSEP (Chapter 4.2.2) followed by the completion of an IKD strength protocol (Chapter 3.7.5). The experimental trials comprised the completion of two treadmill-based SSEP's (Chapter 4.2.2). As depicted in figure 7.1, the control trial comprised 6 x 15 min bouts with a 15 min passive HT interval interspersing the 3rd and 4th bouts, whereas the

interchange trial comprised the completion of 4 x 15 min bouts of activity each interspersed by a 15min period of passive recovery.

To assess the time-course of recovery associated with a number of physical measures, follow up assessments were completed 48 h after the completion of each experimental trial. To account for accommodation and training effects, the two experimental trials and associated follow up assessments were applied in a counter-balanced order. A minimum of 96 h interspersed the completion of the first follow up assessment and the start of the second experimental trial. Prior to the commencement of each experimental trial, participants were required to complete a standardised warm-up (Chapter 3.6). The experimental design and controls are described in more detail in Chapter 3.4.

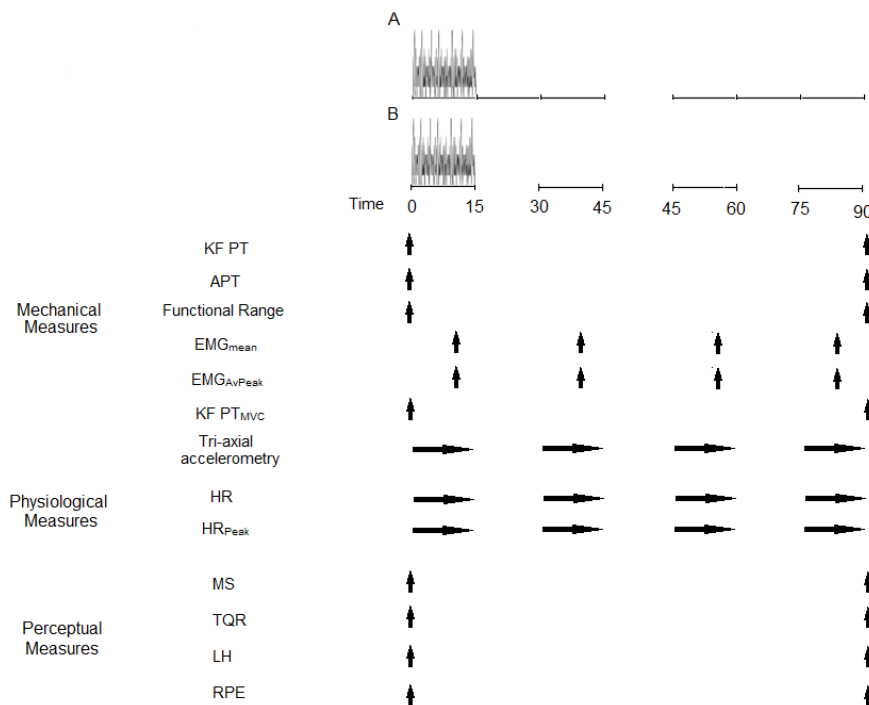


Figure 7.1 Schematic representation of the two experimental trials (A= control; B= Interchange) and associated measurement points. Vertical arrows depict point measurements, and horizontal arrows depict average values recorded across bouts.

7.2.3 Experimental measures

Additional detail in relation to some of the measures is provided in Chapter 3. Average values for HR, HR_{peak}, PL_{total}, PL_{ML}, PL_{AP}, PL_V, PL_{ML}%, PL_{AP}%, and PL_V% were calculated for 0-15, 30-45, 45-60, and 75-90 mins of the SSEP (Chapter 3.7.2 and Chapter 3.7.3). The

participant's RPE was also recorded as a point reading following each of the aforementioned 15min bouts of the SSEP.

Values for EMG_{mean} and average peak EMG ($EMG_{Avepeak}$) were also quantified from the BF muscle at fast ($25 \text{ km}\cdot\text{h}^{-1}$) and moderate ($15 \text{ km}\cdot\text{h}^{-1}$) running speeds (see figure 7.2) during the completion of the aforementioned bouts of activity. Additional detail in relation to the EMG data collection and analysis has been provided previously in chapter 3.7.6.

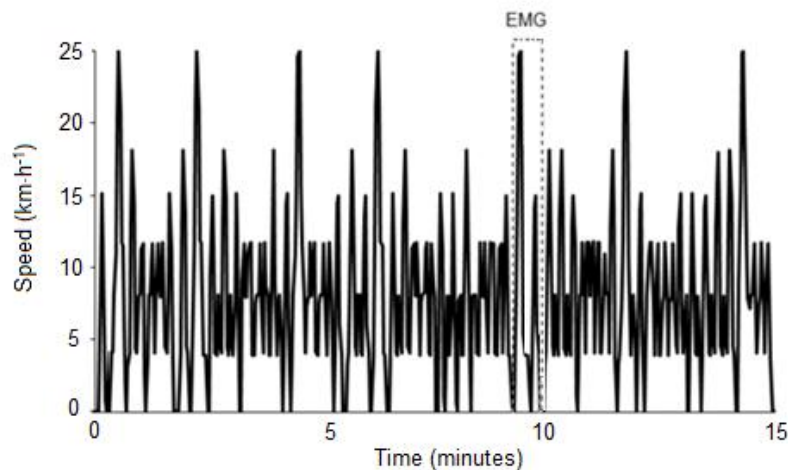


Figure 7.2 Schematic representation of a single 15min bout of the SSEP. The dashed line indicates the EMG data collection period.

Isokinetic dynamometry was utilised to provide values of gravity corrected eccentric KF PT, APT, and FR_{80} data. The isokinetic protocol has been previously described in more detail in chapter 3.7.5. The FR_{80} data was calculated as the range at which the participants were able to maintain 80 percent of their PT, and was calculated for each of the three testing speeds (180 , 300 , and $60 \text{ deg}\cdot\text{s}^{-1}$). The IKD protocol was completed pre-trial, immediately post-trial, and 48 h post-trial.

The IKD was also used to quantify maximal isometric torque (PT_{MVC}). It has previously been identified that alterations in PT_{MVC} data is predominantly influenced by central fatigue mechanisms and, as such, PT_{MVC} offers a potential indirect measure of central fatigue (Rampinini et al., 2011; Goodall et al., 2015). The PT_{MVC} data was recorded following the completion of the aforementioned isokinetic protocol. The participant set up was the same as that associated with the isokinetic protocol. To simulate the lengthened position of the leg as experienced during the terminal swing phase of a sprint cycle (Marshall et al., 2014), the

participants knee angle was fixed at 20° of flexion (with 0° corresponding to full knee extension). At each measurement point participants performed three MVC's. Each MVC was held for 5s with a 1 min passive rest period interspersing each contraction. No verbal encouragement was provided during each trial and the contraction with the highest peak torque was used for further analysis.

Perceptual measures of TQR and MS were quantified pre-trial, immediately post-trial, and 48 h post-trial using VAS scales. The method associated with the MS data is provided in chapter 3.7.4. The participant's perceptions of TQR were provided using a 6-20 scale VAS with "not recovered at all" on the left end of the scale (6) and "completely recovered" at the right hand end of the scale (20). A new VAS was used for each measurement to avoid bias from the previous measurement.

7.2.4 Statistical analysis

Statistical analyses and the variables that were to be included were decided *a priori*. Statistical assumptions were checked using the methods described previously in chapter 4. A two-way (condition*time) GLM was employed to examine differences between the two conditions (control and interchange), and over time (pre-trial, post-trial, 48 h post-trial). Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, Confidence Intervals (95% CI) for difference were also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (≥ 0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean \pm SD unless otherwise stated.

7.3 RESULTS

7.3.1 RPE and physiological responses

As identified in Table 7.1, the GLM identified significant ($P < 0.001$, $\eta^2 = 0.82$) main effects for time for the HR data. The GLM also identified significant main effect for condition ($P = 0.003$, $\eta^2 = 0.73$) for the HR data. Post hoc pairwise comparisons identified significantly higher values in the control trial ($153 \pm 13 \text{ b}\cdot\text{min}^{-1}$) when compared to the interchange trial ($143 \pm 11 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for this difference was 6 to 14 $\text{b}\cdot\text{min}^{-1}$. As identified in figure 7.3, the GLM also identified a significant ($P < 0.001$, $\eta^2 = 0.75$) condition*time interaction for the HR data. Average heart rate values recorded at 30-45, 45-60 and 75-90mins were significantly higher in the control trial ($T_{30-45} = 157 \pm 12 \text{ b}\cdot\text{min}^{-1}$; $T_{45-60} = 151 \pm 12 \text{ b}\cdot\text{min}^{-1}$; $T_{75-90} = 162 \pm 13 \text{ b}\cdot\text{min}^{-1}$) when compared to the interchange trial ($T_{30-45} = 144 \pm 11 \text{ b}\cdot\text{min}^{-1}$; $T_{45-60} = 145 \pm 12 \text{ b}\cdot\text{min}^{-1}$; $T_{75-90} = 146 \pm 11 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for these differences were 9 to 17 $\text{b}\cdot\text{min}^{-1}$, 3 to 10 $\text{b}\cdot\text{min}^{-1}$, 12 to 20 $\text{b}\cdot\text{min}^{-1}$ respectively.

Table 7.1 Time course of changes (irrespective of trial) in the HR, HR_{peak}, and RPE data.

Time (mins)	0-15	30-45	45-60	75-90
HR _{peak} ($\text{b}\cdot\text{min}^{-1}$)	163 ± 10	166 ± 11^a	164 ± 12	168 ± 12^c
HR ($\text{b}\cdot\text{min}^{-1}$)	142 ± 11	151 ± 13^a	148 ± 12^{ab}	154 ± 15^{abc}
RPE (a.u)	11 ± 2	12 ± 2^a	13 ± 2^a	14 ± 3^a

^{abcd} denote significant differences with 0-15, 30-45, 45-60, and 75-90 respectively.

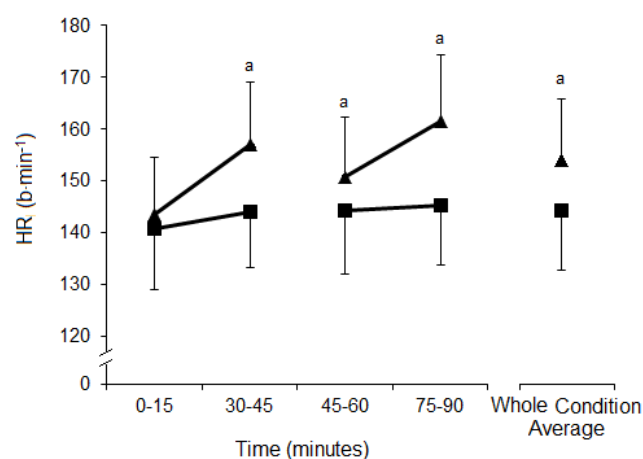


Figure 7.3 Time course of changes in the HR data recorded across the two conditions (■ = Interchange; ▲ = Control). Whole condition averages are also presented. a denotes significant difference with interchange.

As identified in Table 7.1, the GLM identified a significant ($P= 0.003$, $\eta^2 = 0.35$) main effect for time for the HR_{peak} data. The GLM also identified a significant ($P= 0.001$, $\eta^2 = 0.57$) main effect for condition for the HR_{peak} data, with significantly higher values being recorded in the control trial ($168 \pm 11 \text{ b}\cdot\text{min}^{-1}$) when compared to the interchange trial ($162 \pm 11 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for this difference was 2 to 9 $\text{b}\cdot\text{min}^{-1}$. As identified in figure 7.4, the GLM also identified a significant ($P= 0.01$, $\eta^2 = 0.31$) condition*time interaction for the HR_{peak} data, with significantly higher values recorded at 30-45 and 75-90mins in the control trial ($T_{30-45}= 169 \pm 11 \text{ b}\cdot\text{min}^{-1}$; $T_{75-90}= 173 \pm 12 \text{ b}\cdot\text{min}^{-1}$) when compared to the interchange trial ($T_{30-45}= 163 \pm 11 \text{ b}\cdot\text{min}^{-1}$; $T_{75-90}= 163 \pm 11 \text{ b}\cdot\text{min}^{-1}$). The 95% CI for these differences were 1 to 11 $\text{b}\cdot\text{min}^{-1}$ and 7 to 13 $\text{b}\cdot\text{min}^{-1}$ respectively.

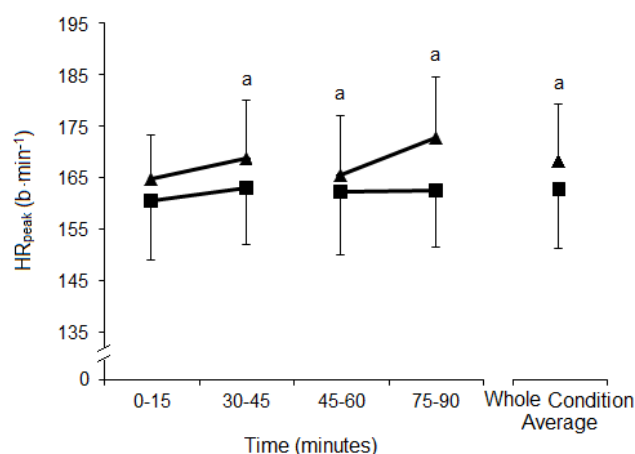


Figure 7.4 Time course of changes in the HR_{peak} data recorded across the two conditions (■ = Interchange; ▲ = Control). Whole condition averages are also presented. ^a denotes significant difference with interchange.

As identified in Table 7.1, the GLM identified a significant ($P= 0.001$; $\eta^2=0.52$) main effect for time for the RPE data. A significant ($P< 0.001$, $\eta^2= 0.68$) main effect for condition was also identified for RPE, with significantly higher values being recorded in the control trial ($13 \pm 2 \text{ a.u}$) when compared to the interchange trial ($12 \pm 2 \text{ a.u}$). The 95% CI for this difference was 1 to 2 a.u. As identified in figure 7.5, the GLM also identified a significant ($P< 0.001$, $\eta^2 = 0.40$) condition*time interaction for RPE, with values recorded at 30-45 and 75-90mins in the control trial ($T_{30-45}= 13 \pm 2 \text{ a.u}$; $T_{75-90}= 15 \pm 3 \text{ a.u}$) being significantly higher than the corresponding time points in the interchange trial ($T_{30-45}= 12 \pm 2 \text{ a.u}$; $T_{75-90}= 13 \pm 2 \text{ a.u}$). The 95% CI for these differences were 1 to 3 a.u and 1 to 3 a.u respectively.

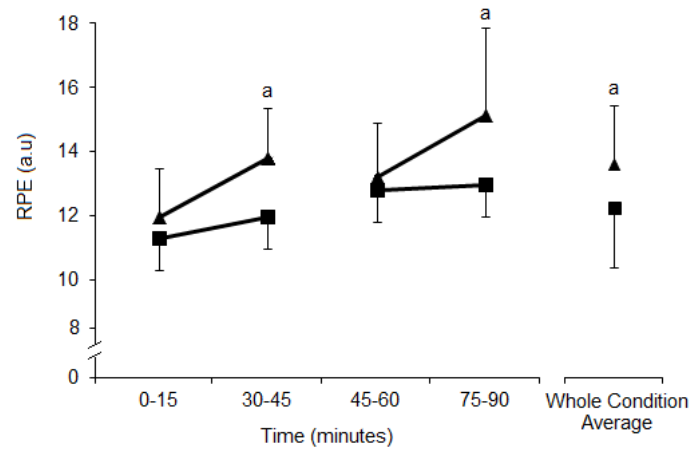


Figure 7.5 Time course of changes in the RPE data recorded across the two conditions (■ = Interchange; ▲ = Control). Whole condition averages are also presented. ^a denotes significant difference with interchange.

7.3.2 Mechanical responses

As identified in table 7.2, there were significant main effects for time associated with PL_{total} ($P=0.04$, $\eta^2=0.43$), PL_{AP} ($P=0.001$, $\eta^2=0.47$), PL_V ($P=0.003$, $\eta^2=0.41$), PL_{ML} ($P=0.04$, $\eta^2=0.25$), $PL_{AP\%}$ ($P<0.001$, $\eta^2=0.41$), and $PL_{V\%}$ ($P=0.004$, $\eta^2=0.35$). There were however no significant ($P=0.07$) main effects for time associated with the $PL_{ML\%}$ data with average values consistent at $21.70 \pm 1.78\%$ respectively. The GLM also identified no significant ($P>0.05$) main effects for condition, and no significant ($P>0.05$) condition*time interactions for PL_{total} , PL_{AP} , PL_V , PL_{ML} , and $PL_{ML\%}$. As identified in figure 7.6, significantly ($P=0.03$, $\eta^2=0.34$) higher $PL_{V\%}$ values were recorded in the interchange trial ($53.94 \pm 2.37\%$) when compared to the control trial ($52.22 \pm 3.21\%$). The 95% CI for this difference 0.20 to 3.24 %. As identified in figure 7.7, a significant ($P=0.02$, $\eta^2=0.24$) trial*Condition interaction was also observed for $PL_{AP\%}$ with significantly higher values being identified at 75-90 mins in the control trial ($26.67 \pm 3.43\%$) when compared to the corresponding time point in the interchange trial ($24.62 \pm 3.29\%$). The 95% CI for this difference was 0.57 to 3.55%.

Table 7.2 Time course of changes (irrespective of trial) in the accelerometry measures.

Time (mins)	0-15	30-45	45-60	75-90
PL_{total} (a.u.)	258.03 ± 25.42	266.78 ± 20.60	270.67 ± 21.71^a	272.58 ± 24.06^a
PL_{AP} (a.u.)	64.57 ± 13.03	66.97 ± 11.65	67.62 ± 11.44^a	69.61 ± 10.44^a
PL_V (a.u.)	136.81 ± 14.30	141.59 ± 14.02	144.37 ± 14.48^a	143.81 ± 16.10
PL_{ML} (a.u.)	56.24 ± 6.06	57.56 ± 5.64	57.96 ± 6.65	58.68 ± 6.55^a
$PL_{AP\%}$ (%)	24.96 ± 3.54	25.17 ± 3.69	25.07 ± 3.70	25.65 ± 3.46^{ac}
$PL_{V\%}$ (%)	53.06 ± 2.96	53.12 ± 3.00	53.42 ± 3.11	52.73 ± 2.81^c

^{abcd} denote significant differences with 0-15, 30-45, 45-60, and 75-90 respectively.

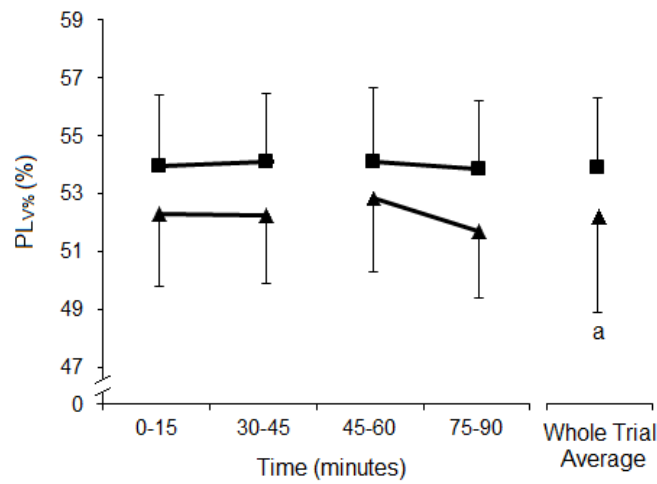


Figure 7.6 Time course of changes in the $PL_{V\%}$ data recorded across the two conditions (■ = Interchange; ▲ = Control). Whole condition averages are also presented. ^a denotes significant difference with interchange.

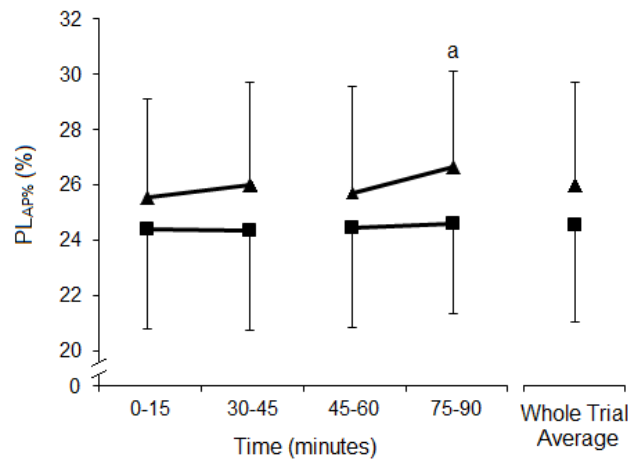


Figure 7.7 Time course of changes in the $PL_{AP\%}$ data recorded across the two conditions (■ = Interchange; ▲ = Control). Whole condition averages are also presented. ^a denotes significant difference with interchange.

As identified in table 7.3 the GLM identified significant main effects for time associated with the EMG_{mean} data recorded at 25 ($P < 0.001$, $\eta^2 = 0.67$) and 15 $km \cdot h^{-1}$ ($P < 0.001$, $\eta^2 = 0.50$), and for the $EMG_{A_{peak}}$ data recorded at 25 ($P < 0.001$, $\eta^2 = 0.51$) and 15 $km \cdot h^{-1}$ ($P < 0.001$, $\eta^2 = 0.67$). The GLM did not identify any significant ($P > 0.05$) main effects for condition, nor Condition*Time interactions for the EMG_{mean} and $EMG_{A_{peak}}$ data recorded at both 25 and 15 $km \cdot h^{-1}$.

Table 7.3 Time course of changes (irrespective of trial) associated with the EMG_{mean} and EMG_{Avpeak} data.

Time (mins)	0-15	30-45	45-60	75-90
EMG _{mean} (μV) 15km·h ⁻¹	62.61 ± 24.60	53.73 ± 18.32	46.43 ± 19.11 ^a	42.51 ± 20.15 ^a
EMG _{mean} (μV) 25km·h ⁻¹	106.15 ± 26.68	90.38 ± 26.97 ^a	86.25 ± 24.21 ^a	80.84 ± 25.37 ^a
EMG _{Avpeak} (μV) 15km·h ⁻¹	152.25 ± 45.03	130.20 ± 39.63 ^a	105.35 ± 39.39 ^{ab}	96.49 ± 43.78 ^{ab}
EMG _{Avpeak} (μV) 25km·h ⁻¹	225.83 ± 60.76	186.55 ± 57.25 ^a	180.56 ± 65.00 ^a	163.06 ± 70.77 ^a

^{ab} denote significant differences with 0-15 and 30-45 mins, respectively.

The GLM identified no significant ($P > 0.05$) main effects for time or condition and no significant Condition*Time interactions for the APT data recorded at 60, 180, and 300 degs·s⁻¹, with average values consistent at $34 \pm 17^\circ$, $38 \pm 18^\circ$, and $39 \pm 11^\circ$, respectively.

The GLM identified no significant ($P > 0.05$) main effects for time or condition, and no significant Condition*Time interactions for the FR₈₀ data recorded at 60, 180, and 300 degs·s⁻¹, with average values consistent at $39 \pm 17^\circ$, $34 \pm 13^\circ$, and $20 \pm 10^\circ$, respectively.

The GLM identified a significant ($P = 0.002$, $\eta^2 = 0.44$) main effect for time associated with the PT_{MVC} data, with significantly higher PT_{MVC} data recorded pre-trial (113.84 ± 14.73 Nm) when compared to post-trial (98.05 ± 18.98 Nm). The 95% CI for this difference was 2.97 to 29.39 Nm. There was however no significant main effect for condition ($P = 0.16$) and no significant ($P = 0.50$) Condition*Time interaction associated with the PT_{MVC} data.

The GLM identified a significant main effect for time for the PT data recorded at 60 ($P = 0.02$, $\eta^2 = 0.31$), 180 ($P = 0.04$, $\eta^2 = 0.26$), and 300 ($P = 0.001$, $\eta^2 = 0.46$) deg·s⁻¹. Post hoc pairwise comparisons identified significantly higher pre-trial values (60 deg·s⁻¹ = 147.23 ± 29.93 Nm; 180 deg·s⁻¹ = 153.62 ± 22.63 Nm; 300 deg·s⁻¹ = 156.66 ± 21.57 Nm) when compared to post-trial (60 deg·s⁻¹ = 135.98 ± 30.96 Nm; 180 deg·s⁻¹ = 141.79 ± 28.81 Nm; 300 deg·s⁻¹ = 142.97 ± 23.26 Nm) and 48 h post-trial (60 deg·s⁻¹ = 136.81 ± 28.73 Nm; 180 deg·s⁻¹ = 144.66 ± 27.26 Nm; 300 deg·s⁻¹ = 147.74 ± 19.14 Nm). As identified in figure 7.8, the GLM also identified a significant main effect for trial associated with the PT data recorded at 180 ($P = 0.04$, $\eta^2 = 0.32$) and 300 ($P = 0.04$, $\eta^2 = 0.35$) degs·s⁻¹, with significantly

higher being recorded in the interchange trial ($180 \text{ deg}\cdot\text{s}^{-1} = 152.11 \pm 25.90 \text{ Nm}$; $300 \text{ deg}\cdot\text{s}^{-1} = 154.13 \pm 21.52 \text{ Nm}$) when compared to the control trial ($180 \text{ deg}\cdot\text{s}^{-1} = 141.27 \pm 26.29 \text{ Nm}$; $300 \text{ deg}\cdot\text{s}^{-1} = 144.12 \pm 21.30 \text{ Nm}$). The 95% CI for these differences were 0.43 to 21.24 Nm and 0.86 to 19.15 Nm, respectively. There was however no significant ($P = 0.86$) main effect for condition for the PT data recorded at $60 \text{ deg}\cdot\text{s}^{-1}$. The GLM also identified no significant ($P > 0.05$) condition*time interactions for the PT data recorded at 60, 180 and $300 \text{ deg}\cdot\text{s}^{-1}$.

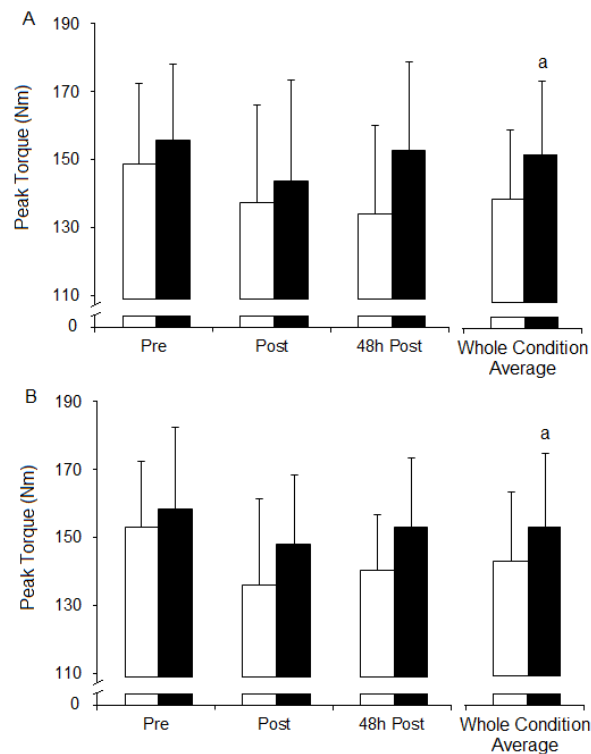


Figure 7.8 Time course of changes in the eccentric KF PT data recorded at 180 (A) and 300 (B) $\text{deg}\cdot\text{s}^{-1}$ in the two conditions (■ = Interchange; □ = Control). Whole condition averages are also presented. ^a denotes significant difference with control.

7.3.3 Perceptual responses

The GLM identified a significant ($P < 0.001$, $\eta^2 = 0.83$) main effect for time for the MS data, with significantly lower values recorded pre-trial ($8 \pm 10 \text{ a.u.}$) when compared to post-trial ($46 \pm 20 \text{ a.u.}$) and 48 h post-trial ($20 \pm 17 \text{ a.u.}$). The 95% CI for these differences were -46 to -30 a.u. and -23 to -3 a.u., respectively. Similarly, Post-trial measures of MS were also significantly higher than the 48 h post-trial measures. The 95% CI for this difference was 14

to 38 a.u. The GLM also identified a significant ($P= 0.05$, $\eta^2= 0.29$) main effect for trial for the MS data, with significantly higher values being recorded in the control trial (29 ± 26 a.u) when compared to the interchange trial (21 ± 19 a.u). There was however no significant ($P= 0.07$) condition*time interaction identified for the MS data.

The GLM identified a significant ($P< 0.001$, $\eta^2= 0.79$) main effect for time for the TQR data, with significantly lower values recorded post-trial (11 ± 3 a.u) when compared to the pre-trial (18 ± 2 a.u) and 48 h post-trial (17 ± 3 a.u). The 95% CI for these differences were -9 to -5 a.u and -8 to -3 a.u, respectively. There was however no main effect for condition ($P= 0.19$), nor condition*time interaction ($P= 0.34$) associated with the TQR data.

7.4 DISCUSSION

The aim of the current study was to assess the influence of player interchange on the physical response and the time course of recovery associated with the completion of a SSEP. Due to the current study being the first to consider the influence of player interchanges in relation to soccer-specific activity, direct comparisons with previous literature are difficult. The SSEP used in the current study has been previously validated based on the velocity profile, distance covered, and the physical response associated with match-play (Chapter 4). The observed physical response can therefore be considered as being representative of that associated with actual match-play.

Similar to studies 1-3 (Chapters 4, 4, and 6, respectively), and in support of match-play observations (Mohr et al., 2003; Mohr et al., 2012; Barrett et al., 2013; Scott et al., 2013), HR, HR_{peak}, and RPE increased as a main effect for exercise duration across each half, with significantly higher values being observed in the control trial. Values for HR (Control= 144 ± 11 b·min⁻¹; Interchange= 144 ± 11 b·min⁻¹), HR_{peak} (Control= 165 ± 9 b·min⁻¹; Interchange= 161 ± 12 b·min⁻¹), and RPE (Control= 12 ± 2 a.u; Interchange= 11 ± 2 a.u) were equivalent in the first 15min bout of the two experimental trials, thus identifying that the participants were fully familiarised prior to the commencement of the experimental trials. Thereafter, significantly higher values for HR and HR_{peak} were observed at 30-45, 45-60 and 75-90 mins in the control trial when compared to the interchange trial. As expected, the HR and HR_{peak} data indicates that the interspersing periods of passive recovery were sufficient to reduce the physiological demand associated with the completion of the exercise protocol. The RPE data was also significantly higher in the final 15 min period of each half during the control trial

when compared to the interchange trial. There was however no significant differences observed immediately following the passive HT period in either trial, thus suggesting that a 15 min period of passive recovery was beneficial in both conditions. The current data also identifies that the observed differences in the RPE response associated with the interchange trial are a direct result of the interspersing 15 min periods of recovery, rather than a reduction in the total volume of work performed. Despite a temporal increase in RPE during the completion of soccer-specific simulations, the RPE response typically remains sub-maximal (Drust et al., 2000b; Greig et al., 2006; Russell et al., 2011). In support of our current data, it has been suggested that RPE develops as a scalar function of the distance remaining during a specific bout of exercise (Waldron and Highton, 2014).

Similar to studies 1, 2, and 3 (Chapters 4, 5, and 6, respectively) and comparable with match-play observations (Barron et al. 2014), all accelerometer values (with the exception of $PL_{ML\%}$) elicited a main effect for time. Values for $PL_{ML\%}$ remained consistent at $\sim 22\%$ across trials. Significantly higher $PL_{V\%}$ data was recorded in the interchange trial ($53.94 \pm 2.37\%$) when compared to the control trial ($52.22 \pm 3.21\%$). The lower $PL_{V\%}$ in the control trial was also more marked during the final 15min period, suggesting a fatigue influence. The lower contribution of $PL_{V\%}$ observed in the control trial seems to suggest that an altered running style is adopted between the two conditions indicative of a flatter mass centre trajectory during each stride. The differences in $PL_{V\%}$ may be due to a feedforward driven modification of movement strategy to enhance economy in the control trial, due to their knowledge of the remaining exercise duration. In support of this, Gabbett et al., (2015) identified that players alter their pacing strategy based on the anticipated end point of the exercise bout. Furthermore, Waldron and Highton (2014) referred to a central control system that regulates running performance in an anticipatory manner. Cormack et al. (2013) refer to a “Groucho” style of running and a reduced vertical stiffness, reflecting a decrease in $PL_{V\%}$, in this case as a result of fatigue, but a conscious technical modification to conserve energy.

In further support of the observed alterations in running technique, Smith et al., (*In Press*) observed reductions in activity during the early parts of match-play, to maintain HI running capacity towards the end of a match. Waldron and Highton (2014) identified that part-match players adopt a “one bout, all-out” strategy, whereas whole-match players utilise a “slow-positive” pacing strategy. Orchard and colleagues (2012) identified that substitute players who enter the field with a different pacing strategy punctuate the progressive decline in HI running observed across a team. Bradley and Noakes (2014) identified that substitutes

covered 15% more HI running when compared with an equivalent time point. In the present study, the higher $PL_V\%$ in the interchange trial is indicative of a running technique more mechanically suited to the HI bouts, and less economical during the LI bouts of exercise. If the increased $PL_V\%$ data can be related to increased vertical stiffness, the players will be generating peak torque at longer muscle lengths, thus potentially increasing force production, improving stability, and aiding athletic performance (La Stayo et al., 2003). The compensatory increase in $PL_{AP}\%$ during the final 15 mins of the control trial, may be indicative of fatigue induced changes in running technique observed towards the end of soccer-specific activity (Woods et al., 2004; Small et al., 2009). The current $PL_{AP}\%$ data also supports observations of impaired HI running (Mohr et al., 2003) and increased injury risk (Ekstrand et al., 2011) during the latter stages of match-play. The increase in $PL_{AP}\%$ is reflective of greater mechanical loading in the sagittal plane, associated with linear accelerations and deceleration and KF strain aetiology (Small et al., 2009). This mechanism is protected during the final 15 mins of the interchange protocol, thus advocating the use of player interchanges in soccer as a strategy to reduce injury risk and aid performance.

Irrespective of condition, perceptual measures in the form of TQR and MS were both shown to be significantly different immediately post-trial ($TQR = 11 \pm 3$ a.u; $MS = 46 \pm 20$ a.u) when compared to pre-trial ($TQR = 18 \pm 2$ a.u; $MS = 8 \pm 10$ a.u). Perceptions of TQR were shown to be recovered 48 h post-trial ($TQR = 17 \pm 3$ a.u), whereas MS remained significantly higher ($MS = 20 \pm 17$ a.u). The INT velocity profiles emphasise a high frequency of eccentric contractions, associated with muscle damage (Eston et al., 2003; Amann, 2011) and subsequent increases in MS. The current MS response occurs in parallel to the observed changes in PT, thus supporting the findings reported in study 3 (Chapter 6). Furthermore, there were no significant differences in the TQR data recorded between the two conditions (Control = 15 ± 4 a.u; Interchange 16 ± 4 a.u); however, the MS data were highest in the control condition ($MS = 29 \pm 26$ a.u) when compared to the interchange condition ($MS = 21 \pm 19$ a.u). In support of study 3 (Chapter 6), the observed difference in MS between the two conditions may be indicative of the increased volume of activity performed in the control condition. The current data suggests that a myriad of perceptual measures may be required to monitor a player's level of recovery in preparation for a successive bout of activity (Rey et al., 2012b).

Values for EMG_{mean} and EMG_{Avpeak} recorded at 15 and 25km·h⁻¹ were shown to reduce as a function of exercise duration in both trials, with significant reductions in muscular activity in

the second half when compared to the first 15 min period. There was however no difference in the fatigue response elicited by the two conditions. It has previously been suggested that an interchanged player may experience a transient decrease in KF injury risk, but the opposition player may experience a transient increase because they have to match the activity profile of the interchanged player (Orchard et al., 2012). The BF muscle activity data recorded in the current study appears to contradict this suggestion, due to the lack of mechanical recovery observed in the interchange trial. The current EMG data supports previous observations of reduced BF muscle activity following the first 15 min period of soccer-specific activity (Marshall et al., 2014), thus potentially explaining the lack of differences observed between the two experimental trials. For example, the largest decrement in EMG activity occurs within the first 15 mins of the simulations, as such BF muscle activity may have been significantly impaired prior to the completion of the first passive rest period associated with the interchange trial. The subsequent 15 min periods of recovery do not appear to be of sufficient duration to recover muscular activity.

As previously discussed in study 3 (Chapter 6), each 15 min period of the current exercise protocol is characterised by six high velocity sprint efforts. These HI efforts may therefore be sufficient to significantly reduce BF muscle activity (Marshall et al., 2015; Goodall et al., 2015). Reductions in muscular activity during the completion of soccer-specific activity have been attributed to alterations in central motor output in an attempt to offset the peripheral fatigue response (Marshall et al., 2014). Increases in peripheral biochemical markers influence type III and IV nerve afferents that ultimately reduce central motor output to allow for sufficient levels of peripheral recovery (Gandevia, 2001; Amman, 2011; Sidhu et al., 2013). Early and significant reductions in BF activity may also occur as a protective mechanism to ensure that activity levels can be maintained for the duration of a soccer match, supporting the preservation of HI running in match-play (Smith et al., *In Press*). This temporal pattern mirrors the observations of tri-axial accelerometry and the compensatory changes between $PL_{V\%}$ and $PL_{AP\%}$. The observed reduction in BF muscular activity may also have implications for the concurrent changes in eccentric KF PT and PT_{MVC} data.

Irrespective of condition, and in support of previous observations (Rahnama, 2003; Greig, 2008; Small et al., 2010; Rampinini et al., 2011; Marshall et al., 2014), eccentric KF PT (recorded at all testing speeds) and PT_{MVC} were significantly lower immediately after exercise. Knee flexor PT was significantly lower 48 h post-trial when compared to pre-trial. In support of previous observations (Rampinini et al., 2011), the current PT_{MVC} data was

shown to be fully recovered 48 h post-trial. It has been identified that reductions in PT_{MVC} following soccer-specific activity are primarily related to central fatigue mechanisms (Rampinini et al., 2011; Goodall et al., 2015), and that measures influenced by central fatigue are often fully recovered within 24 h (Minet and Duffield, 2014). There were no significant differences in the fatigue response associated with the PT_{MVC} data and the PT data recorded at $60 \text{ deg}\cdot\text{s}^{-1}$ between the two conditions.

Significantly higher PT values were recorded at ‘moderate’ ($180 \text{ deg}\cdot\text{s}^{-1}$) and ‘fast’ ($300 \text{ deg}\cdot\text{s}^{-1}$) speeds in the interchange trial when compared to the control trial, with higher values being observed across all measurement points in the interchange condition. In support of the EMG_{mean} and EMG_{Avpeak} data reported previously, the moderate speed PT data was reduced by a similar magnitude ($\sim 8\%$) across the two experimental trials. These data support the notion that reductions in central motor output in the first bout of each condition may result in similar mechanical fatigue responses across the two trials, and that a passive 15min period does not aid the recovery of PT during the completion of soccer-specific activity (Greig, 2008). In contrast it was identified that fast speed PT was fatigued to a greater extent in the control trial ($\sim 11\%$) when compared to the interchange trial (6%). In support of the observed differences in the LH and MS data, the differences in the rate of fatigue associated with the fast speed PT data may be attributable to the increased volume of work associated with the control trial. It has been identified that increased volumes of activity elicit a greater level of structural impairment and peripheral fatigue (Lepers et al., 2000; Oliveira et al., 2009), particularly within the type II muscle fibres (Eston et al., 2003).

Similar to the RS data reported in the previous chapter, both the moderate and fast speed PT data recovered to a greater extent post-trial in the interchange condition when compared to the control condition. Fast and moderate speed PT recovered to within ~ 3 and 2% of pre-trial values respectively in the interchange trial, but both continued to reduce following the completion of the control trial. The increased volume of activity associated with the control trial may have resulted in the manifestation of additional peripheral mechanisms during the 48 h recovery period when compared to the interchange condition (Rampinini et al., 2011; Nédélec et al., 2012). As previously mentioned, it has been suggested that reductions in central output occur to offset the occurrence of peripheral mechanisms (Marshall et al., 2014). It therefore seems feasible that an elevated peripheral fatigue response following the completion of the control trial will result in a reduction in central output and an impaired rate of recovery. The fatigue effect observed in the interchange condition may have

predominantly been central in nature due to the lower volume of activity performed, and as previously mentioned, central fatigue recovers at a far greater rate when compared to peripheral fatigue (Minet and Duffield, 2014). The current PT data has implications for training design whereby the rate of post-trial mechanical recovery may be improved by designing training that is characterised by intermittent periods of activity punctuated by time matched periods of recovery.

The current study observed no fatigue effect in APT, in contrast to Small et al., (2010), Cohen et al., (2015), and Coratella et al., (2015) who reported alterations in APT with a trend for shorter muscle lengths with soccer-specific fatigue. These differences may be explained by the exercise protocols used, with Small et al. (2010), Cohen et al., (2015), and Cortella et al., (2015) using free-running SSEP's characterised by a high frequency of COD. This high frequency of COD will result in the participants performing a high number of accelerations and decelerations, thus increasing the mechanical load (Terje et al., *In Press*). The SSEP's utilised by Small et al., (2010) and Cohen et al., (2015) were shown to induce a decrease in eccentric KF PT recorded at $120 \text{ deg}\cdot\text{s}^{-1}$ by ~17 and 18%, amongst a similar participant group. The large reduction in eccentric KF strength might therefore be sufficient to induce a change in muscular contractile properties, eliciting a movement along the KF length-tension curve towards shorter muscle lengths. In the present study the greatest reduction of eccentric KF PT was ~10.5% recorded at $300 \text{ deg}\cdot\text{s}^{-1}$, with no subsequent change in APT.

There was also no observed variation in the FR data, an additional indicator of the torque-angle curve. The FR data, calculated at both 80% of PT offers a novel consideration of isokinetic data. The current data reported no influence of time or trial on the FR₈₀ data, thus suggesting that players are able to maintain similar FR even with alterations in PT. Participants were able to maintain 80% of their PT across ~20° at the fastest test speed, and ~39° at the slowest speed. A 20% reduction in PT is often used (anecdotally) as a marker of muscular injury, and similar reductions in KF PT have been observed following the completion of soccer-specific exercise (Small et al., 2010; Cohen et al., 2015). The ability to maintain 80% of PT across a wide range of motion would therefore have obvious implications for injury risk. The calculation of FR may be used in the future to better identify players who are susceptible to KF injury risk; however, this suggestion warrants further investigations.

7.5 CONCLUSION

The findings from this present study suggest that the inclusion of interchanges in soccer has potential benefits for reducing the physiological (HR and HR_{peak}) and perceptual (RPE, LH, and MS) response to the SSEP. The current data also suggest that prior knowledge of the use of interchanges may result in the players making anticipatory modifications to their running technique, with the interchange trial eliciting a running technique more mechanically suited to the HI bouts and less economical during the low intensity bouts of exercise. The interchange trial appeared to prevent fatigue induced increases in sagittal plane loading, thus potentially advocating the use of this rule change intervention to reduce injury risk (Ekstrand et al., 2011) and aid performance (Mohr et al., 2003; Krustrup et al., 2006b; Bradley et al., 2009) during the latter stages of match-play. Conversely, the interspersing periods of passive recovery as associated with the interchange condition were not of sufficient duration to recover BF muscle activity. In support of study 3 (Chapter 6), the post-trial rate of recovery associated with the moderate and fast speed KF PT data appeared to be greater in the interchange trial, with implications for potentially reducing injury risk in soccer. This suggestion is supported by Orchard et al., (2012) who identified that ARF players who were regularly interchanged were at a lower risk of KF injury risk. The use of player interchanges may therefore be beneficial to reduce injury risk during periods of congested match-play (Dupont et al., 2010; Bengsston et al., 2013; Dellal et al., 2015). Although many may deem it difficult to get the interchange rule approved in soccer, in 2015 the International Football Association Board authorised a “return sub” rule change at grass roots level. This rule allows teams to utilise an unlimited interchange strategy during competitive matches. Furthermore, as has been previously mentioned, the work and rest durations of other intermittent team-sport athletes are manipulated via the use of interchange substitutions.

CHAPTER EIGHT

STUDY FIVE

ASSESSING THE EFFECTIVENESS OF AN ACTIVE RECOVERY PROTOCOL FOR SOCCER MATCH-PLAY

8.1 INTRODUCTION

Study 3 (chapter 6) identified that the residual fatigue response associated with periods of short-term fixture congestion is mechanical and muscular in nature. To reduce injury risk and potentially aid successive performance, the mechanical fatigue response must therefore be manipulated. This can be achieved by reducing the volume of activity performed (Study 4), which would require an enforced rule change by governing bodies, or by artificially aiding the rate of post-match mechanical recovery. Recovery strategies should be informed by the nature of the exercise completed and should be specific to the physical measurements that are required to be recovered. Study 5 has therefore been designed to assess the effectiveness of a mechanically orientated active recovery protocol on assisting the rate of mechanical and perceptual recovery following the completion of a single bout of soccer-specific activity.

As previously discussed, modern soccer is characterised by high frequency of training and/or match-play, with intense bouts of activity typically being performed multiple times over a weekly training cycle (King and Duffield 2009). High frequencies of training and match-play result in reduced time for recovery between successive bouts, resulting in high physical demands being placed on the players (Reilly and Ekblom, 2005), and a subsequent increase in injury risk (Dupont et al., 2010, Bengsston et al., 2013; Dellal et al., 2015). A player's ability to recover between successive bouts of training and/or match-play is therefore essential for successful future performance (Andersson et al., 2008).

Barnett (2006) stated that for an athlete to optimally prepare for upcoming training and competition, they may have to implement strategies that artificially speed up the natural time-course of recovery. Previous literature has assessed the effectiveness of a number of recovery strategies in soccer including, but not limited to cold water immersion (Ingram et al., 2009; Rowsell et al., 2011; Ascensão et al., 2011; Kinugasa and Kilding, 2009), nutrition (Gunnarsson et al., 2011), compression garments (Valle et al., 2013), stretching (Kinugasa and Kilding, 2009), electrical stimulation (Tessitore et al., 2007), active recovery (Reilly and Rigby 2002, Tessitore et al., 2007; Andersson et al., 2008, Rey et al 2012a; Rey et al., 2012b), and contrast water therapy (Kinugasa and Kilding, 2009). Two of the most commonly utilised and potentially most easily implemented strategies are active recovery and massage. Nédélec et al., (2013) completed a survey with practitioners who were in charge of recovery strategies at 32 elite French clubs, and identified that 81% utilised active recovery and 78% massage as recovery strategies with their players.

It is commonly believed that active recovery sessions enhance the recovery process and accelerate the return to homeostasis following the completion of soccer-specific activity (Andersson et al., 2008). Typically characterised by the completion of short duration (~20min) submaximal bouts of cycling or running, a number of previous studies have therefore attempted to assess the effectiveness of active recovery following the completion of soccer-specific activity (Reilly and Rigby, 2002, Tessitore et al., 2007; Andersson et al., 2008, Rey et al 2012a; Rey et al., 2012b). Due to differences in methodologies, the aforementioned studies have typically reported equivocal findings. Some studies have identified no beneficial effects of active recovery (Andersson et al., 2008; Rey et al., 2012a), whereas others have identified that active recovery is beneficial in attenuating the development of MS (Tessitore et al., 2007) and may aid the recovery of some acute physical performance tasks (Reilly and Rigby, 2002; Rey et al., 2012b). Rey et al., (2012b) suggested that the equivocal findings associated with active recovery literature may be related to the measures used in a number of these studies not being indicative of match-play, and that future research should focus on measures of muscular fatigue and contractile function.

Galloway and Watt (2004) stated that massage corresponds to a “mechanical manipulation of body tissue with rhythmical pressure and stroking for the purpose of promoting health and well-being.” To promote recovery after soccer match play a number of massage techniques are commonly used in a number of elite teams (Nédélec et al., 2013). The majority of literature points towards massage being effective in alleviating muscle soreness and perceptions of recovery, although its effects on muscle function and performance are unclear (Nédélec et al., 2013). The inconsistent findings associated with the effectiveness of massage may be attributable to methodological differences, such as differences in massage techniques and skills of the therapist.

In the survey conducted by Nédélec et al., (2013), it was identified that practitioners typically combine a number of recovery strategies in an attempt to optimise the effectiveness of their recovery sessions. It has also previously been identified that the completion of a combination of recovery strategies may be beneficial in aiding the rate of post exercise recovery (Dawson et al., 2005; Kinugasa and Kilding, 2009; Jakeman et al., 2010). The characteristics of different recovery strategies may also be amalgamated in an attempt to better design an effective recovery intervention. For example, the combination of deep massage and passive stretching is common to Thai massage and has previously been shown to be effective in reducing psychological stress and muscle tension in clinical populations (Buttagat et al.,

2012), and improving physical fitness in soccer players (Hongsuwan et al., 2015). It therefore seems feasible that the principles associated with active recovery and massage could be amalgamated in an attempt to aid post-match recovery in soccer players.

Given the inconsistent findings associated with previous recovery literature, and based on the findings of study 3, the current study aimed to determine the effectiveness of a novel active recovery protocol performed 24 h after the completion of a SSEP on mechanical and perceptual recovery. In an attempt to design an effective recovery intervention, the current recovery protocol has been informed by principles associated with massage and active recovery.

8.2 METHOD

8.2.1 Participants

Twelve male semi-professional soccer players (mean \pm SD: age 23.2 ± 4.8 yrs, height 181.6 ± 3.8 cm, body mass 82.0 ± 7.6 kg) volunteered to complete this study during the English competitive soccer season. Participant's eligibility was determined from the inclusion and exclusion criteria described in Chapter 3.1. Furthermore, participants were also required to not possess any bilateral eccentric KF strength imbalances ($>10\%$) at any of the isokinetic testing speeds. This was assessed immediately prior to the completion of a 30 min treadmill-based familiarisation, following the completion of an IKD familiarisation session. As described in Chapter 3.3, preliminary anthropometric and health screening procedures were completed prior to each trial. The study was approved by the University Research Ethics Committee and conformed to the declaration of Helsinki. Written informed consent was obtained for all participants prior to the commencement of data collection.

8.2.2 Experimental design

Participants attended the laboratory on five occasions to complete an IKD familiarisation trial, a 30min treadmill-based familiarisation trial, an experimental trial, an intervention trial, and a follow up assessment. The IKD familiarisation session was completed on the participant's dominant (preferred kicking leg) and non-dominant lower limbs, and comprised the completion of the isokinetic protocol described previously in Chapter 3.7.5. The 30 min treadmill-based familiarisation and the experimental trial were both completed on a programmable motorised treadmill (Chapter 3.5).

The treadmill-based familiarisation trial comprised 2 x 15 min bouts of the SSEP (Chapter 4.2.2) preceded by the completion of an isokinetic strength assessment (Chapter 3.7.5). As previously mentioned, the preceding IKD strength protocol was used to identify any large (>10%) bilateral differences in eccentric KF PT between the participants dominant and non-dominant limbs. Participants were excluded from the testing if they were unable to complete the 30 min familiarisation trial and/or elicited large bilateral differences in KF PT. The experimental trial comprised the completion of a treadmill-based SSEP (Chapter 4.2.2). The intervention trial (as described in more detail in the subsequent section) comprised the completion of a novel IKD based active recovery protocol and was completed 24h after the completion of the experimental trial. It has previously been identified that active recovery or massage performed immediately after exercise may have a detrimental effect on the rate of recovery (Fairchild et al., 2003; Nédélec et al., 2013). Furthermore, to assess the time-course of recovery associated with a number of physical measures, a follow up assessment was completed 48 hr after the completion of the experimental trial. Each of the familiarisation trials and the start of the experimental trial were interspersed by a period of 96 h. Prior to the commencement of each experimental trial, participants were required to complete a standardised warm-up (chapter 3.7). The experimental design and controls are described in more detail in chapter 3.4.

Recovery protocol

The recovery protocol was completed using an IKD (System 3, Biodex Medical Systems, Shirley, New York, USA), and was designed to amalgamate a myriad of principles associated with previously utilised recovery strategies. Participants were secured onto the IKD in accordance with the manufacturers guidelines. As previously described (Chapter 3.7.5), participants were secured on the IKD in accordance with the manufacturers guidelines. However, in an attempt to place the KF musculature in a more functionally relevant position (Matsuo et al., 2015), and in support of previous observations (Thelan et al., 2005), the participants were seated in a position that elicited a hip flexion angle of $70 \pm 4^\circ$ (with 90 degrees representing a neutral and upright seated position). As depicted in figure 8.1, a supportive cuff was secured against the KF musculature to ensure that the hip was positioned in the required position. This cuff was also used to provide pressure to the KF musculature in an attempt to replicate the pressure applied by a masseuse during the completion of a massage recovery strategy.



Figure 8.1 IKD set up during the active recovery protocol

To reduce the number of trials performed by the participants, and in accordance with previous literature (Farr et al., 2002; Eriksson Cromert et al., *In Press*), the recovery protocol was administered to the non-dominant lower limb (treatment limb), with the dominant limb acting as a control (control limb). It has previously been identified that there is no difference in the mechanical fatigue (concentric and eccentric KF and KE PT) response elicited by the dominant and non-dominant limb following the completion of a SSEP (Rahnama et al., 2003).

Previous active recovery protocols have typically been completed for a total duration of ~20 mins (Tessitore et al., 2007; Rey et al., 2012a; Ret et al., 2012b), thus providing ~10mins of activity for each limb. The current active recovery protocol was therefore designed to be ~10 mins in duration. Furthermore, it has also been stated that for a massage to elicit any positive effects it must be delivered for a minimum of 10mins (Moraska, 2005).

The active recovery protocol comprised the completion of 400 passive knee flexion and extension repetitions using the passive exercise mode of the IKD. The participants were therefore required to remain seated in the position described previously, whilst the IKD passively moved their leg through different ranges of motion. The number of repetitions was based on previous active recovery and sports massage literature. Hemmings et al., (2000) utilised massage as a recovery strategy with amateur boxers. The authors stated that a combination of effleurage (30 strokes/min) and petrissage (50-60 strokes/min) techniques were used. As such, a treatment comprised of 50% of each technique would result in 400-450 strokes over a 10 min period. Furthermore, Kinugasa and Kilding (2009) identified that their

active recovery protocol was completed on a cycle ergometer at 60-80 revolutions per minute. At this cadence a total 300-400 revolutions would be performed by each leg over a 10 min period.

The 400 passive repetitions were sub-divided into the following three sets:

1. 150 knee flexion and extension repetitions performed across a full range of motion (25-115 degrees) at an angular velocity of $150 \text{ deg}\cdot\text{s}^{-1}$.
2. 100 knee flexion and extension repetitions performed across a reduced range of motion (65-115 degrees) at an angular velocity of $300 \text{ deg}\cdot\text{s}^{-1}$.
3. 150 knee flexion and extension repetitions performed across a full range of motion (25-115 degrees) at an angular velocity of $150 \text{ deg}\cdot\text{s}^{-1}$.

The ranges of motion were calculated from unilateral sagittal plane kinematic data (Qualisys AB, Gothenburg, Sweden) recorded from the SSEP during pilot testing. It was identified that during the completion of a maximal sprint phase of the SSEP, a knee-angle time history of $\sim 65\text{-}115^\circ$ in flexion was observed. Likewise, a maximum knee extension angle of $\sim 25^\circ$ was identified during the stance phase of the sprint. The differences in the angular velocities completed between sets was informed by the Hemmings et al., (2000) study who reported that a petrissage massage technique is performed at a stroke rate roughly twice as fast as an effleurage technique. The authors also identified that an effleurage technique is performed across the longitudinal axis of the muscle, whereas petrissage is typically performed in a kneading or squeezing motion to the bulk of the muscle, thus supporting the decision to include different ranges of motion. The full range of motion was also chosen to passively lengthen the KF musculature in an attempt to counteract any fatigue induced adaptive shortening of the KF musculature (Small et al., 2009).

During sets 1 and 3, the increased range of motion and low angular velocity was designed to ensure that the KF musculature will pass over the cuff of the support, thus simulating an effleurage massage technique. Similarly during set 2, the reduced range of motion and increased angular velocity will result in the bulk of the KF musculature being applied directly against the cuff of the support, thus simulating a petrissage massage technique.

8.2.3 Experimental measures

As described previously in study 4 (chapter 7), an IKD was utilised to provide values of gravity corrected eccentric KF PT, APT, and FR data for both the control and treatment limb.

The FR data was calculated as the ranges at which the participants were able to maintain 80 percent (FR_{80}) of their PT, and was calculated for each of the three testing speeds (60, 180, and 300 $\text{deg}\cdot\text{s}^{-1}$). The IKD protocol was completed pre-trial, immediately post-trial, and 48 h post-trial. As described in study 4 (Chapter 7) the IKD was also used to quantify PT_{MVC} 's for the participant's dominant and non-dominant KF muscles. The PT_{MVC} assessments were completed following the completion of the other IKD measures.

As described previously in study 4 (chapter 7), perceptual measures of TQR and MS were quantified for the participant's dominant and non-dominant limbs. These perceptual measures were recorded pre-trial, immediately post-trial, and 48 h post-trial using VAS scales.

8.2.4 Statistical analysis

Statistical analyses and the variables that were to be included were decided *a priori*. Statistical assumptions were checked using the methods described previously in chapter 4. A two-way (condition*time) GLM was employed to examine differences between the two conditions (control limb and treatment limb), and over time (pre-trial, post-trial, 48 h post-trial). Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, 95% CI for difference were also presented. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (≥ 0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean \pm SD unless otherwise stated.

8.3 RESULTS

8.3.1 Mechanical responses

Maximal strength was quantified as PT and PT_{MVC} . The GLM identified a significant main effect for time for the PT data recorded at 60 ($P = 0.03$, $\eta^2 = 0.29$), 180 ($P = 0.02$, $\eta^2 = 0.31$), and 300 ($P = 0.002$, $\eta^2 = 0.44$) $\text{deg}\cdot\text{s}^{-1}$. The PT data recorded at 180 and 300 $\text{deg}\cdot\text{s}^{-1}$ were significantly higher pre-trial ($PT_{180} = 152.23 \pm 24.59$ Nm; $PT_{300} = 153.13 \pm 20.67$ Nm) when compared to post trial ($PT_{180} = 140.57 \pm 26.36$ Nm; $PT_{300} = 135.90 \pm 24.64$ Nm). The 95% CI for these differences were 2.15 to 20.57 Nm and 5.46 to 29.00 Nm respectively. Furthermore PT data recorded at all angular velocities were significantly higher pre-trial ($PT_{60} = 146.89 +$

28.42) when compared to 48 h post-trial ($PT_{60} = 131.69 \pm 28.80$ Nm; $PT_{180} = 140.13 \pm 30.66$ Nm; $PT_{300} = 141.59 \pm 15.41$ Nm) The 95% CI for these differences were 1.72 to 28.69, 0.86 to 21.58 Nm and 1.19 to 21.89 Nm respectively. There was however no significant ($P > 0.05$) main effect for condition and no significant ($P > 0.05$) condition*time interaction for any of the PT data.

A similar response was also identified for PT_{MVC} data, whereby irrespective of condition, significantly ($P = 0.01$, $\eta^2 = 0.46$) higher values were recorded at rest (112.95 ± 19.14 Nm) when compared to the post-trial (94.86 ± 19.28 Nm). The 95% CI for this difference was 4.35 to 31.83 Nm. There was however no significant ($P = 0.62$) main effect for condition and no significant ($P = 0.86$) condition*time interaction.

The GLM identified no significant main effect for time for the APT data recorded at 60 ($P = 0.83$), 180 ($P = 0.60$), and 300 ($P = 0.60$) $\text{deg}\cdot\text{s}^{-1}$, with average values consistent at $36 \pm 11^\circ$, $39 \pm 19^\circ$, and $37 \pm 10^\circ$ respectively. Furthermore, there were no significant ($P > 0.05$) main effects for condition associated with any of the APT recorded across all testing speeds, and no significant ($P > 0.05$) condition*time interactions for the APT data recorded at 60 and 180 $\text{deg}\cdot\text{s}^{-1}$. As identified in Figure 8.2, there was however a significant ($P = 0.03$, $\eta^2 = 0.28$) Condition*Time interaction identified for the APT data recorded at 300 $\text{deg}\cdot\text{s}^{-1}$ with significantly lower values being identified 48 h post-trial for the intervention limb ($34 \pm 10^\circ$) when compared to the control limb ($40 \pm 12^\circ$). The 95% CI for this difference was -10 to -1° .

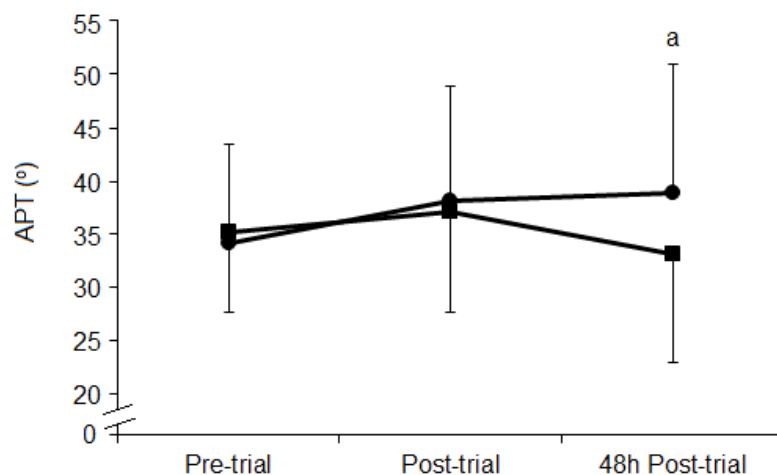


Figure 8.2 Time course of changes in the APT data recorded across the two conditions (■ = Intervention; ● = Control). ^a denotes significant difference with intervention.

The GLM identified a significant ($P= 0.05$, $\eta^2 = 0.23$) main effect for time for the FR_{80} data recorded at $300 \text{ deg}\cdot\text{s}^{-1}$ (Figure 8.3). Post hoc pairwise comparisons identified significantly lower values being recorded post-trial ($18 \pm 7^\circ$) when compared to the pre-trial ($23 \pm 8^\circ$). The 95% CI for this difference was -9 to -1° . The GLM did not identify a significant main effect for time for the FR_{80} data recorded at 60 ($P= 0.23$) or 180 ($P= 0.11$) $\text{deg}\cdot\text{s}^{-1}$, with average values consistent at $39 \pm 17^\circ$ and $34 \pm 12^\circ$ respectively. Furthermore, the GLM did not identify any significant main effects for condition ($P> 0.05$) and no significant condition*time interaction ($P> 0.05$) for any of the FR_{20} data.

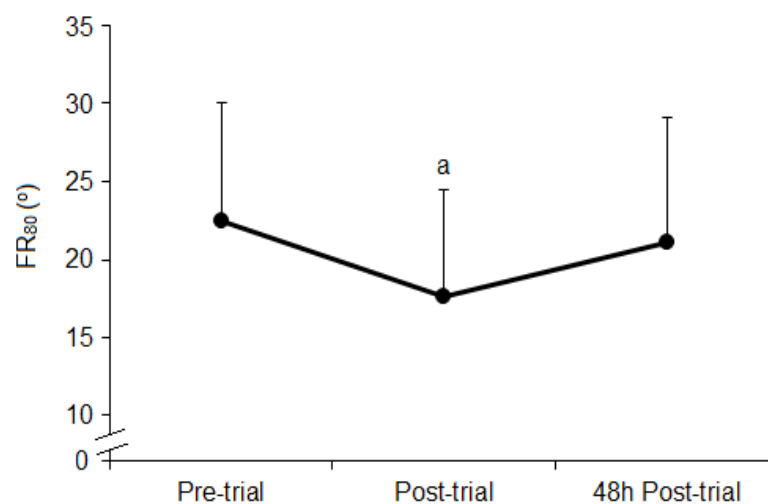


Figure 8.3 Time course of changes (irrespective of condition) in the FR_{80} data recorded at $300 \text{ deg}\cdot\text{s}^{-1}$ across the three measurement points. ^a denotes significant difference with pre-trial..

8.3.2 Perceptual responses

Perceptual measures displayed similar temporal patterns. A significant ($P<0.001$, $\eta^2 = 0.71$) main effect for time was identified for the MS data, with significantly higher values recorded immediately post-trial ($52 \pm 22 \text{ a.u.}$) when compared to pre-trial ($10 \pm 12 \text{ a.u.}$), and 48 h post-trial values ($23 \pm 20 \text{ a.u.}$). The 95% CI for these differences were 29 to 55 a.u and 11 to 48 a.u, respectively. There was however no significant main effect for trial ($P= 0.65$) and no trial*time interaction ($P= 0.77$).

A similar response was also observed for the TQR data, whereby a significant ($P<0.001$, $\eta^2 = 0.78$) main effects for time was identified. Post hoc pairwise comparisons identified significantly higher values pre-trial ($19 \pm 1 \text{ a.u.}$) when compared to immediately post-trial ($11 \pm 3 \text{ a.u.}$) and 48 h post-trial ($16 \pm 3 \text{ a.u.}$). The 95% CI for these differences were 6 to 10 a.u

and 0 to 4 a.u., respectively. Significantly higher values were also recorded 48 h post-trial when compared to post-trial. The 95% CI for this difference were 3 to 9 a.u. There was however no significant main effect for trial ($P=0.13$) and no trial*time interaction ($P=0.98$).

8.4 DISCUSSION

The aim of the current study was to determine the effectiveness of a novel active recovery protocol on mechanical and perceptual recovery. In support of previous observations (Dawson et al., 2005; Kinugasa and Kilding, 2009; Jakeman et al., 2010), the recovery protocol was designed to amalgamate principles associated with a number of recovery strategies, specifically active recovery and massage. Due to the novel nature of the current active recovery protocol, direct comparisons with previous literature are difficult. The SSEP used in the current study has been previously validated based on the velocity profile, distance covered, and the physical response associated with match-play (Chapter 4). The observed physical response can therefore be considered as being representative of that associated with actual match-play.

The current study identified that there were no significant differences in any of the perceptual or mechanical measures recorded pre- or post-trial between the dominant (control) and non-dominant (treatment) legs. These data therefore suggests that with equivalence at baseline, there was no significant difference in the mechanical or perceptual fatigue response elicited by the SSEP. The lack of significant differences in the pre- to post-trial mechanical fatigue response elicited by the dominant and non-dominant legs support previous observations following the completion of a treadmill-based SSEP (Rahnama et al., 2003). Therefore observations post-intervention can be attributed to the active recovery protocol employed in this study.

There were no significant differences in the post-trial APT data recorded at all angular velocities (60, 180, and 300 deg·s⁻¹) when compared to pre-trial. These data support the observations made in study 4 (Chapter 7), and contrast previous observations (Small et al., 2010; Cohen et al., 2015; Coratella et al., 2015). As previously discussed in chapter 4, the inconsistencies between the current data and that associated with previous research may be indicative of the nature of the SSEP's used, and the lack of changes in direction associated with the current SSEP protocol. There were also no significant differences in the slow and moderate speed APT data recorded 48 h post-trial between the dominant and non-dominant

limbs. It was however identified that the fast speed APT recorded 48 h post-trial were significantly lower ($\sim 6^\circ$) in the treatment limb when compared to the control limb. This data therefore suggests that the current active recovery protocol appears to have a positive effect on the maximal elongation capacity of the muscle at high angular velocities.

It has been previously identified that fatigue induces changes in running kinematics as characterised by a reduction in maximum knee flexion angle, a reduction in maximum knee extension, a reduction in stride length, a higher stride frequency, and a prolonged contact time (Woods et al., 2004; Small et al., 2009). The observed changes in hip flexion and knee extension have been suggested to be indicative of a fatigue induced reduction in maximum KF elongation capacity (Small et al., 2010), indicative of shorter KF muscle lengths (Small et al., 2010; Coratella et al., 2015) and higher APT data. The fatigue induced alterations in maximum KF elongation capacity will therefore result in the muscle operating on the descending limb of the length-tension curve, thus increasing injury risk when the KF muscles are forcefully elongated during the terminal swing phase of a sprint cycle (Small et al., 2010). Previous literature has identified that soccer-specific exercise elicits changes in APT of ~ 10 - 12° (Small et al., 2010; Coratella et al., 2015). The current active recovery protocol may, therefore, be beneficial in assisting the restoration of the maximum elongation capacity of the KF musculature and, thus, potentially reducing injury risk, particularly during periods of fixture congestion. This observation may be indicative of the beneficial effects of the current active recovery protocol in relation to passively working the KF musculature through a full range of motion. Where previous active recovery protocols have been utilised in the literature, they have typically been characterised by the completion of LI cycling and/or running (Rigby and Reilly, 2002; Tessitore et al., 2007; Andersson et al., 2008; Kinugasa and Kilding, 2009; Rey et al., 2012ab). These protocols are therefore characterised by reduced ranges of knee flexion and extension, thus potentially further actively shortening the KF musculature. Future research should focus on manipulating the duration and/or frequency of the current active recovery protocol to identify if increased alterations in the APT data can be achieved. Moraska (2005) previously identified that massage should be delivered for a minimum of 10 mins for it to elicit any positive effects. As such, if the current protocol was delivered for a more prolonged period then the characteristics of the protocol which were based on massage principles, may have potentially elicited a greater effect.

Typically the torque-angle curve is quantified as PT and APT, which restricts analysis to where the muscle is strongest. Arguably it is the regions of muscular weakness where injury

is most likely. In the current study the activity profile also elicited a change in FR, which when associated with APT, might be indicative of changes to muscle function, if not maximal strength. The functional quality of muscle might be given further consideration, beyond that of maximal strength. To retain the isokinetic range, this FR inevitably becomes reduced at the higher testing speeds. However, the observed changes in FR post-exercise and APT post-intervention suggest potential benefits of monitoring these measures with athletic populations.

In contrast to the data presented in study 4 (Chapter 7) and irrespective of condition, the FR₈₀ data recorded at 300 deg·s⁻¹ was significantly lower post-trial ($18 \pm 7^\circ$) when compared to pre-trial ($23 \pm 8^\circ$). As previously discussed in study 4 (Chapter 7), the use of the FR data offers a novel consideration of the torque-angle curve. The observed reduction in FR₈₀ data suggests that the use of FR measures may have potential implications for identifying players who may be susceptible to KF injury risk. The FR₈₀ data recorded 48 h post-trial was not significantly different to pre-trial values, with no significant difference between limbs. These data therefore suggest that the FR₈₀ data was fully recovered within 48 h, with the active recovery protocol not providing any additional benefit. However, this (maintained) FR might have shifted along the torque-angle curve, in association with the observed shift in APT. The current data suggests that eccentric KF FR data should be calculated alongside the more traditional IKD screening measures to help identify players who may be susceptible to increased injury risk.

Irrespective of condition, and in support of previous observations (Rahnama et al., 2003; Greig, 2008; Small et al., 2010; Rampinini et al., 2011), the PT_{MVC} and eccentric KF PT data recorded at all testing speeds (60, 180, and 300 deg·s⁻¹) were significantly lower post-trial when compared to pre-trial, with no significant differences observed between dominant and non-dominant legs. In support of previous observations (Rampinini et al., 2011), the PT_{MVC} data was not significantly different 48 h post-trial when compared to the pre-trial, with no significant differences observed between the dominant and non-dominant legs. The active recovery protocol did not influence the rate of recovery associated with the PT_{MVC} data. As previously discussed in study 4 (Chapter 7), reductions in PT_{MVC} data following SSEP are primarily related to central fatigue (Rampinini et al., 2011; Goodall et al., 2015). Minet and Duffield (2014) identified that central fatigue is typically recovered within 24 h, and as such, the current PT_{MVC} data may therefore have already been recovered prior to the completion of the active recovery protocol. The PT data recorded at all angular velocities was significantly

lower 48 h post-trial when compared to pre-trial, with no significant difference between dominant and non-dominant legs. The current data, therefore, suggests that the active recovery protocol did not influence the rate of post-trial recovery associated with the PT data. It is also acknowledged that the 400 repetitions incorporated within the recovery protocol might have elicited their own post-exercise influence. The lack of recovery in PT might therefore be attributed to a compensatory effect between active recovery and additional muscular work. Whilst passive, the muscle will engage in acceleration and deceleration of the dynamometer crank arm. Furthermore, as previously discussed in studies 3 and 4 (Chapters 6 and 7, respectively), the manifestation of biochemical and peripheral markers during the 48 h recovery period may have resulted in a reduced central output to the KF muscles (Rampinini et al., 2011; Nédélec et al., 2012). A reduction in central motor output would in turn impair the rate of recovery. Future research should therefore consider the recovery of central motor output when designing recovery strategies (Minet and Duffield 2014).

Irrespective of condition, perceptual measures in the form of TQR and MS were shown to be significantly different immediately post-trial ($TQR = 11 \pm 3$ a.u.; $MS = 52 \pm 22$ a.u) when compared to both pre-trial ($TQR = 19 \pm 1$ a.u; $MS = 10 \pm 12$ a.u) and 48 h post-trial ($TQR = 16 \pm 3$ a.u; $MS = 23 \pm 20$ a.u). The MS data recorded 48 h post-trial was also not significantly different to the data recorded pre-trial, with no significant differences between the dominant and non-dominant limbs. The TQR data was however significantly lower 48 h post-trial when compared to pre-trial, but again there were no significant differences identified between the dominant and non-dominant limbs. The active recovery protocol therefore did not influence the rate of recovery associated with the TQR and MS data, with 48 h recovery appearing to be sufficient to recover perceptions of MS, but not TQR. Anecdotal observations from the current participants were that they perceived the recovery to have had a beneficial effect immediately after its administration; however, there was no perceived difference 24 h after the completion of the recovery intervention. The timing of the follow up assessment may have therefore been too long after the completion of the recovery strategy to identify any acute perceptual benefits. The current perceptual measures data both supports (Rey et al., 2012a) and contrasts previous literature (Kinugasa and Kilding, 2009; Tessitore et al., 2007) in relation to the effectiveness of active recovery in altering the rate of perceptual recovery. However, due to methodological differences, direct comparisons with previous literature are difficult. In support of study 4 (Chapter 7), the current data further supports that due to the

differences in the time course of recovery associated with the different measures, a number of perceptual measures should be utilised by practitioners to assess the rate of recovery associated with their players (Rey et al., 2012b). However, the perceptual masking of incomplete mechanical recovery might put the athlete at risk of injury.

8.5 CONCLUSION

The primary finding of this study is that the active recovery protocol appears to elicit beneficial alterations in fast speed APT data. Thus, the use of the current active recovery protocol may help to restore the maximum elongation capacity of the KF musculature following the completion of soccer-specific activity, and may be beneficial in reducing injury risk, particularly during periods of fixture congestion. The measures of FR_{80} as used in the present study warrant further investigation. The active recovery protocol did not appear to have any beneficial nor deleterious effect on the recovery of maximal strength and perceptual measures.

CHAPTER NINE

GENERAL DISCUSSION

9.1 INTRODUCTION

This chapter will synthesise and interpret the findings of this thesis whilst also addressing the realisation of the aims and objectives. The subsequent section will comprise the completion of a general discussion which will contextualise the practical implications associated with the current series of investigations. The final section of this chapter will address the limitations of the thesis and propose directions for future research.

9.2 REALISATION OF AIMS AND OBJECTIVES

The series of investigations associated with this thesis were designed to examine the physical response associated with periods of soccer-specific fixture congestion and attempt to develop potential methods to reduce the physical response to, and aid the time course of recovery following the completion of soccer-specific activity. The current investigations were conducted in a laboratory environment using semi-professional soccer players. The completion of laboratory based assessments enabled increased experimental rigour and the assessment of a number of physical measures that are often impractical or prohibited in an applied setting. The specific objectives of this thesis were to: 1) To design and validate the physical demand associated with a contemporary treadmill-based SSEP; 2) To examine the physical demands associated with successive bouts of soccer-specific activity, and assess the influence of an additional day of recovery; 3a) To investigate the physical demand associated with the completion of a simulated period of fixture congestion; 3b) To assess and compare the physical demand associated with the completion of successive bouts of different exercise modalities, specific to the demands of the SSEP; 4) To assess the effectiveness of a contemporary rule change intervention on reducing the physical response to, and aiding the time course of physical recovery following the completion of a SSEP; 5) To develop and assess the effectiveness of a novel active recovery protocol on aiding the rate of post-trial mechanical recovery. A total of five studies were completed to achieve the aforementioned aims and objectives. The following conclusions can be made from the five experimental chapters:

Study 1:

The SSEP provided a valid simulation of soccer match-play based upon both the input (the TD covered and structure of the velocity profile) and the output (the physical response). With the exception of the $PL_{ML\%}$ and PL_V data, significant main effects for time were identified for

all physical measures (RPE, HR, BLa, $\dot{V}O_{2peak}$, $\dot{V}O_2$, PL_{total} , PL_{ML} , PL_{AP} , $PL_{AP\%}$, and $PL_{V\%}$). A similar magnitude of change at ~5% was observed for both the HR and PL_{total} data. The SSEP was shown to elicit ~23% of all PL_{total} data in the medial-lateral plane, thus negating previous criticism of treadmill-based SSEP's as being uni-directional and eliciting a linear running style.

Study 2:

A significant main effect for time was identified for the majority of measures (RPE, HR, HR_{peak} , BLa, $\dot{V}O_{2peak}$, $\dot{V}O_2$, PL_{total} , PL_{ML} , PL_{AP} , PL_V , $PL_{AP\%}$, and $PL_{V\%}$), with no significant differences between successive trials interspersed by either 48 or 72 h recovery. There were also no significant differences in the fatigue response elicited across the two successive trials. Acknowledging the specificity of the physical measures, 48 h appears sufficient recovery between successive bouts of soccer-specific exercise.

Study 3:

The residual fatigue response associated with the completion of three successive bouts of the SSEP over a 5 day period was mechanical and muscular in nature (BF muscle activity, eccentric KF PT, and MS). The observed changes in KF PT and perceptions of MS during the three SSEP trials appears to be most greatly influenced by the volume of activity performed, with the continuous modality eliciting a similar yet more marked response. The observed residual fatigue response identified for the BF muscle activity in the third SSEP trial appears to be most greatly influenced by the number of repeated HI efforts performed across the three trials, with the RS modality eliciting a similar response. The continuous modality consistently elicited the greatest physiological and mechanical response, with the RS modality eliciting the lowest. It was identified that for all modalities there were no significant differences in the fatigue response associated with the PlayerLoadTM, RPE, and physiological measures across the three successive trials.

Study 4:

The use of interchanges significantly reduced the physiological (HR and HR_{peak}) and perceptual (RPE and MS) response to soccer-specific activity. Significant differences were also observed in the tri-axial accelerometry response recorded during the two trials, with significantly lower $PL_{AP\%}$ data and significantly higher $PL_{V\%}$ data being recorded in the interchange trial. The interspersing recovery periods were not of sufficient duration to

recover BF muscle activity, BF eccentric PT, or the PT_{MVC} data. The magnitude of fatigue (~8-9%) associated with the KF PT data was similar between the two conditions; however, the KF PT data recorded 48 hours post-trial in the interchange trial was recovered to a greater extent when compared to that recorded at the measurement point in the control trial.

Study 5:

With the exception of the APT and FR₈₀ data recorded at 60 and 180 deg·s⁻¹, significant main effects for time were identified for all mechanical and perceptual measures, with no significant differences observed between dominant and non-dominant legs. Completion of the novel active recovery protocol appeared to elicit beneficial changes in the fast speed APT data, but did not appear to have either a beneficial or detrimental effect on the recovery of the other mechanical (eccentric KF PT and FR₈₀ data recorded at 60, 180, and 300 deg·s⁻¹, APT data recorded at 60 and 180 deg·s⁻¹, and PT_{MVC} data) and perceptual measures (MS and TQR).

9.3 GENERAL DISCUSSION

Due to a high frequency of matches associated with modern soccer, players are often required to compete with only 2-4 days recovery between successive matches. Fixture congestion therefore poses a contemporary concern within soccer (Carling et al., 2015) with implications for performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) and injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015). In an attempt to increase ecological validity, previous literature has typically attempted to assess the influence of fixture congestion on performance and injury risk during actual soccer match-play. Actual match-play is susceptible to contextual factors (Rollo et al., 2014) and is characterised by large between-match and between subject variability (Gregson et al., 2010), as such previous fixture congestion literature has typically identified inconsistent findings. It is also often impractical or prohibited to record certain physical measures during soccer match-play (Stølen et al., 2005; Rollo et al., 2014). It has therefore recently been suggested that SSEP's could be utilised to assess the physical mechanisms associated with simulated periods of fixture congestion (Carling et al., 2015)

The influence of fatigue on both performance and injury risk in soccer has been well documented, driving the development of laboratory-based models designed to replicate the

physical demands of match-play (Abt et al., 1998; Bishop et al., 1999; Drust et al., 2000ab; Nicholas et al., 2000; Greig et al., 2006; Small et al., 2009; Williams et al., 2010; Russell et al., 2011; Bendiksen et al., 2012; Clarke et al., 2012; Aldous et al., 2014). However, common to most attempts to replicate the physical demands of soccer match-play using SSEP's are validation issues. Study 1 therefore focussed on the development and validation of a novel treadmill-based SSEP.

Results from study 1 identified that the SSEP provided a valid representation of the TD covered (Saltin, 1973; Whitehead, 1975; Withers et al., 1982; Ekblom, 1986; Van Gool et al., 1988; Bangsbo et al., 1991; Mohr et al., 2003; Di Salvo et al., 2007; Barros et al., 2007; Rampinini et al., 2007; Bradley et al., 2009; Barnes et al., 2014), and the physical response (Mohr et al., 2003; Stølen et al., 2005; Krstrup et al., 2006b; Bangsbo et al., 2007; Mohr et al., 2012; Barrett et al., 2013; Scott et al., 2013; Barron et al., 2014) associated with match-play. The 'clustering' of the HI bouts of activity (Spencer et al., 2004), the LI to high HI work duration (Reilly, 1997), and the frequency, duration, and speed of the discrete locomotive phases (Mohr et al., 2003) all suggest that the SSEP also provided a valid representation of the velocity profile associated with match-play. The observed changes in the physical measures appear to support previous observations of temporary (Mohr et al., 2003) and cumulative fatigue (Mohr et al., 2003; Barros et al., 2007; Rampinini et al., 2007ab) during soccer match-play. Furthermore, due to the standardised nature of the protocol, the observed changes in the PlayerLoadTM measures appear to suggest a fatigue induced alteration in running technique, indicative of an increased injury risk during the latter stages of match-play (Hawkins et al., 2001; Ekstrand et al., 2011). As previously mentioned, the development of a valid SSEP could be utilised to answer questions which are pertinent to contemporary soccer, with emphasis surrounding physical performance and injury risk. It has been identified that 70% of all injuries in soccer are as a result of physical contact (Aoki et al., 2012); valid SSEP's can therefore be used as a training tool whilst providing a reduced injury risk.

Given the potentially detrimental effects associated with periods of short-term fixture congestion, the aim of study two was to quantify the physical fatigue response associated with repeated match simulations interspersed by 48 h or 72 h recovery. The physical response associated with soccer-specific activity has received a considerable amount of attention (Mohr et al., 2003; Greig et al., 2006; Krstrup et al., 2006b; Bangsbo et al., 2007; Ispirlidis et al., 2008; Ascensão et al., 2011); however, the physical response associated with periods of

fixture congestion has not been afforded as much consideration (Andersson et al., 2008). The SSEP developed and validated in study 1 was used to simulate and standardise the successive bouts of soccer specific activity. The physical measures were chosen to replicate those commonly used to monitor fatigue and training load within an applied sport setting (Halson, 2014), and were similar to those utilised in the first study. The results for study 2 identified that the physical fatigue response was comparable to that elicited in study 1. The physical response associated with study 2 can therefore be considered as being a valid representation of match-play. The data reported in study 2 identified that there were no significant difference in the physical response elicited across the two successive trials, with no significant difference in the fatigue response across the two trials interspersed by either 48 or 72 h recovery.

Study 2 therefore identified that 48 h was sufficient to recover the measures recorded, with no additional physical demand associated with the completion of a successive bout of soccer-specific activity. The data associated with study 2 therefore has potential implications for the design and micro management of training and competition schedules. However, the nature of contemporary soccer is such that more than two bouts of successive soccer specific activity may be completed over a weekly period. It has previously been identified that three matches in a week typically represents the worst case scenario for fixture congestion (Odetoyinbo et al., 2007; Carling and Dupont, 2011; Rollo et al., 2014; Folgado et al., 2015), with more prolonged periods of fixture congestion typically being characterised by longer recovery periods interspersing successive matches (Carling et al., 2012; Dellal et al., 2015).

Study 3 was therefore designed to assess the physical response to, and time course of physical recovery associated with three successive bouts of soccer-specific activity, completed with 48 hrs recovery between each trial. Study three replicated the physical measures associated with studies 1 and 2 and also utilised the same SSEP to simulate the period of short-term fixture congestion based. Given the implications of fixture congestion on injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015), additional mechanical measures were recorded in the third study. It was identified that the completion of three games in five days had no residual effect on the physiological or PlayerLoad™ response; however, the mechanical response was characterised by insufficient recovery of PT recorded at 300 deg·s⁻¹ with 48 h recovery, and the third trial elicited further detriments in MS, BF muscular activity, and PT recorded at both 60 and 300 deg·s⁻¹. These data therefore suggest a biomechanical

and muscular emphasis with residual fatigue, and support previous observations of increased injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015) and reduced physical performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) during periods of fixture congestion. Similar to study 2, these data have implications for the micromanagement and design of training and competition schedules. These data also further support the importance of developing KF musculature that is resistant to fatigue during periods of fixture congestion.

An additional aim associated with study 3 was to assess and compare the physical response associated with successive bouts of different exercise modalities, specific to the demands of the current SSEP. Where research has previously considered the physical response associated with soccer-specific exercise in comparison to different exercise modalities, only a single bout of intermittent and steady-state activity has been considered (Drust et al., 2000b; Greig et al., 2006). These studies have either utilised a SSEP that does not offer a valid replication of the highly intermittent nature of soccer match-play, or have utilised a steady-state trial at the same average velocity as that associated with the SSEP ($\sim 6\text{-}8 \text{ km}\cdot\text{h}^{-1}$). The average velocity associated with the completion of $\sim 12\text{km}$ in 90mins is equivalent to a walking pace (Kirkendall, 2000), and is therefore not a valid model of training. Similarly, the HI bouts in soccer have been shown to not be arbitrarily distributed, but rather completed in ‘clusters’ (Spencer et al., 2004).

The SSEP designed in study 1 was therefore considered as a hybrid of the continuous 12 km TD covered (CONT) and the repeated sprint nature to the HI bouts (RS). Intermittent, continuous, and repeat sprint activity are all used in soccer specific conditioning, and thus a mechanistic comparison of these different modalities may potentially have implications for the design of soccer-specific training. Similarly, by comparing the discrete characteristics of soccer match-play, an increased understanding can be gained in relation to which specific characteristics are responsible for the observed cumulative and residual fatigue responses associated with a period of short-term fixture congestion.

Similar to the response elicited across the successive SSEP trials, it was identified that there was no residual effect on the physiological and PlayerLoadTM response elicited from the CONT and RS modalities. The CONT modality resulted in a consistently higher physiological response when compared to the other two modalities, with this response potentially being attributable to the high volume of activity and unaccustomed nature of the

CONT modality. The physiological response was consistently lowest in the RS modality when compared to the other two modalities, with this response potentially being related to the lower volume of activity and interspersing periods of passive recovery associated with the RS modality. The physiological response elicited from the RS and SSEP were most similar. These data therefore have implications for training prescription with the RS modality potentially offering a time efficient method for eliciting an equivalent physiological response to match-play, whereas the CONT modality may be used as a method of increasing the aerobic fitness of soccer players.

A similar yet more marked cumulative fatigue response was observed for the MS and fast speed PT data recorded during the successive CONT trials when compared to the SSEP; however, this response was not observed across the RS trials. These data therefore suggest that the residual fatigue response associated with the fast speed PT and MS data is most greatly influenced by the volume of activity performed across the successive trials. In relation to the BF muscle activity, both the RS and INT modality elicited reductions towards the end of the third trial, thus suggesting that the BF muscle activity is most greatly influenced by the number of HI efforts performed across the successive trials. The mechanical data therefore suggests that two successive bouts of RS activity can be performed following the completion of 48 h recovery without any significant differences in the mechanical response. For the other two modalities there was an observed lack of mechanical recovery as early as the second trial. Furthermore, similar to the physiological response, the CONT modality elicited the greatest cumulative and residual mechanical fatigue response when compared to the other two modalities. These data therefore have implications for the design and micromanagement of soccer-specific training.

Study 3 also identified that the rate of post-trial mechanical recovery could potentially be enhanced by the punctuating activity with periods of passive recovery. It was therefore acknowledged that it may be possible to reduce injury risk and aid successive performance by reducing the volume of activity performed during a match. Study 4 was therefore designed to assess the effect of a contemporary rule change (interchange rule) intervention on reducing the physical fatigue response (both cumulative and residual) associated with the completion of the SSEP. It has previously been identified that the use of regular interchanges in ARF reduces the incidence of KF strain injuries (Orchard et al., 2012). Although there are a number of distinct differences between ARF and soccer, the velocity profile associated with these sports are very similar. It therefore seems feasible that interchanges may also offer a

method of reducing injury risk in soccer. Due to the current study being the first to consider the influence of player interchanges in relation to soccer-specific activity, direct comparisons with previous literature are difficult.

The punctuation of the activity profile with periods of passive recovery appears to elicit beneficial reductions on measures of HR, HR_{peak}, RPE, and MS during the completion of the SSEP. It was also identified that the knowledge of the exercise duration appeared to elicit a feedforward modification in running technique. A potentially more economical style appeared to be adopted in the control trial, indicative of lower PL_V% data. It has previously been identified that team sport players may alter their pacing strategy based on the anticipated end point of an exercise bout (Gabbett et al., 2014) and that this alteration in running performance is governed in an anticipatory manner by a central control system (Waldron and Highton, 2014). Study 4 also identified significantly higher PL_{AP}% data in the final bout of the control condition, indicative of increased mechanical loading in the sagittal plane, associated with linear accelerations and deceleration KF and strain aetiology (Small et al., 2009). This mechanism was not observed in the interchange protocol, thus advocating the use of player interchanges in soccer as a potential strategy to reduce injury risk and aid performance.

Conversely, the interspersing periods of passive recovery did not appear to be of sufficient duration to recover measures of BF muscle activity, eccentric KF PT, or the KF PT_{MVC} data. It has previously been identified that both eccentric KF PT and BF muscle activity are significantly impaired following the completion of a single set (5 repetitions) of Nordic hamstring exercise (Marshall et al., *In Press*). Similarly, Goodall et al., (2015) also identified that two 30m maximal sprints were sufficient to significantly impair voluntary strength of the KE. These previous studies therefore suggest that the high number of eccentric contractions associated with the first 15min bout of the SSEP may be sufficient to significantly impair measures of BF muscle activity, eccentric KF PT, and KF PT_{MVC} prior to the completion of the first interchange period. In support of previous observations of reduced KF injury risk in ARF players who were regularly interchanged (Orchard et al., 2012), the post-trial rate of recovery associated with the moderate and fast speed KF PT data appeared to be greater in the interchange trial. The use of player interchanges may therefore be beneficial to reduce injury risk during periods of congested match-play (Dupont et al., 2010; Dellal et al., 2015).

The data reported in study 3 also informed the development of study 5. As previously discussed, the residual fatigue response associated with periods of short-term fixture

congestion is mechanical and muscular in nature. To reduce injury risk and potentially aid successive performance the mechanical fatigue response can be manipulated by either reducing the volume of activity performed (study 4) which would require an enforced rule change by governing bodies, or by artificially speed up the natural time-course of recovery (Barnett, 2006). Based on the observations from study 3, study 5 was designed to assess the effectiveness of a mechanically orientated active recovery protocol on assisting the rate of mechanical and perceptual recovery following the completion of the SSEP designed in study 1. The perceptual and mechanical measures were similar to those utilised in study 4. Based on previous observations the recovery protocol was designed to amalgamate a number of principles associated with previous recovery modalities (Dawson et al., 2005; Kinugasa and Kilding, 2009; Jakeman et al., 2010; Nédélec et al., 2013), specifically active recovery and massage.

The current active recovery protocol was completed using and IKD and comprised the completion of 400 passive knee extension and flexion repetitions completed at different angular velocities and ranges of motion. The recovery protocol was administered 24 h after the completion of the SSEP, with a follow up mechanical and perceptual assessment being performed 24 h after the completion of the recovery protocol. It was identified that the recovery intervention appeared to elicit a beneficial effect on fast speed APT data, indicative of an improved elongation capacity of the KF musculature. It has previously been identified that soccer-specific activity can elicit fatigue induced increases in the APT data, indicative of shorter KF muscle lengths (Small et al., 2009; Coratella et al., 2015). Reductions in KF elongation capacity towards the end of soccer match-play will result in increased injury risk when the KF musculature is forcefully elongated during the terminal swing phase of a sprint cycle (Small et al., 2010). The current active recovery protocol may therefore be beneficial in reducing injury risk, particularly during periods of fixture congestion (Dupont et al., 2010; Dellal et al., 2015). The active recovery protocol did not appear to have a beneficial effect on the recovery of maximal strength or any perceptual measures; however, the active recovery protocol also did not impair the rate of recovery associated with any of the measures.

9.4 FUTURE RECOMENDATIONS AND LIMITATIONS

There are a number of limitations associated with the current series of investigations, with implications for future research. Although study one identified that the SSEP was a valid representation of soccer match-play, the reliability of the physical response was not assessed.

Furthermore, the current velocity profile was based on the notational data of an average elite soccer player based on data collected from a range of outfield playing positions. Whilst the use of this data provided a standardised velocity profile, thus increasing the experimental control, players from different playing positions may have elicited different physical responses. Future research might therefore consider the physical response associated with players of different playing positions during the completion of the SSEP. The current protocol also only provides a valid representation of male soccer match-play; however, the velocity profile (and/or acceleration capabilities of the treadmill) could be manipulated for applications in youth or female soccer for example, or in return to play management of injured players. The protocol could also be utilised in future research alongside an environmental stressors, for example in relation to performing in hyperthermic conditions during tournaments such as the Qatar World Cup. Future research may also consider the inclusion of sporadic periods of different intensities of activity in an attempt to better replicate the reactive and temporary fatigue response associated with soccer match-play.

Studies 2 and 3 investigated the influence of successive bouts of soccer-specific activity, with study 3 also assessing the effects of successive bouts of different exercise modalities. A potential limitation of both studies was that although attempts were made to standardise the participants behaviour between successive trials, as with all testing there is a reliance on participants to adhere to the controls outside of the laboratory. In study 3 the physical response appeared to be influenced by the unaccustomed nature of the CONT modality, thus suggesting that additional familiarisation trials could have been completed. Furthermore, the results from study 3 are specific to semi-professional male soccer players who possess very specific levels of fitness and conditioning, these results may therefore not be transferable to other athletic populations. An additional limitation of study 3 was that the high number and specific scheduling of trials and the recruitment of a homogenous sample restricted the number of participants who were able to successfully complete the study. Future research may therefore attempt to assess the response elicited from a larger number of participants performing successive bouts of different modes of exercise. Additional research could also focus on increasing the rigour associated with the analysis of some of the physical measures such as, but not limited to the EMG and IKD data. For example, analysing the frequency of the EMG signal will help provide a more comprehensive understanding of the fatigue response associated with periods of short-term fixture congestion. Future research may also consider alternative measures of muscle damage and muscular function during periods of

fixture and/or training congestion. The current studies would also have benefited from the assessment of reliability and standard error of measurement data associated with some of the physical measures. This in turn, would identify the error associated with the current measures and allow for a more accurate assessment of the data.

With specific reference to study 4, future research could attempt to assess the physical response associated with the completion of player interchanges over a more prolonged period, with specific focus on markers of injury risk. Similarly, the principle of punctuating activity with periods of recovery may also be assessed during soccer-specific conditioning with the aim of assisting the rate of recovery following the completion of the protocol. A potential limitations associated with study 4 could be that it is difficult to infer if the change in some of the physical measures is a result of interspersing periods of recovery or a result of the reduced total volume of activity. In an attempt to further develop our understanding of this potential rule change, future research should assess the physical response associated with interchanges of different frequencies and duration.

Study 5 focussed on the development and assessment of a novel active recovery strategy using an IKD. Although the use of an IKD increased experimental control and standardised the dose of activity, a potential limitation could be that the recovery strategy is reliant on the use of an IKD. Future research should therefore assess if the principles associated with this recovery strategy can be transferred to other more easily administered methods. In support of previous observations (Rahnama et al., 2003), there was no observed difference in the pre- to post-trial fatigue response elicited by the dominant and non-dominant legs. However, if there was a difference in the rate of recovery associated with the two limbs, this may have masked any effects of the recovery intervention. Based on recent recommendations (Millet and Duffield 2014), future research should also attempt to recover central fatigue mechanisms, thus potentially aiding the recovery of muscular activity and strength following the completion of soccer-specific activity.

The current thesis has provided an increased mechanistic understanding of the cumulative and physical response associated with periods of short-term fixture congestion in adult male semi-professional soccer players. However, fixture congestion also poses a contemporary concern in female and youth soccer. The current methodology could therefore be applied with both a youth and female cohort. Furthermore, to further improve our understanding of injury mechanisms in soccer; future research could also assess the influence of short-term fixture

congestion on other injuries such as, but not limited to, knee and ankle ligamentous injuries and anterior cruciate ligament injuries.

9.5 CONCLUSIONS

The current thesis has identified that there is no residual fatigue response associated with the RPE, HR, HR_{peak}, $\dot{V}O_2$, $\dot{V}O_{2peak}$, and PlayerLoadTM data during the completion of successive bouts of soccer-specific exercise interspersed by 48h recovery. The mechanical response associated with the completion of three bouts of soccer-specific activity was characterised by insufficient recovery of PT recorded at 300deg·s⁻¹ with 48h recovery, and further detriments in MS, BF muscular activity, and PT recorded at both 60 and 300deg·s⁻¹ in the third trial. The current data therefore supports previous observations of reduced physical performance (Odetoyinbo et al., 2007; Carling et al., 2010; Rollo et al., 2014) and increased injury risk (Dupont et al., 2010; Dellal et al., 2015) during periods of fixture congestion. The current data has implications for the practitioner in relation to the design and micromanagement of training and competition schedules, and may also help to inform the choice of physical measures to monitor recovery in soccer.

It was identified that the observed reductions in eccentric KF PT and MS were most greatly influenced by the volume of activity completed across the three successive trials, whereas the reductions in BF muscle activity appeared to be related to the number of HI efforts performed across the successive trials. A contemporary rule change intervention involving the use of player interchanges was therefore assessed to see if the cumulative and residual mechanical fatigue response could be reduced by manipulating the volume and number of HI efforts performed across a single bout of soccer-specific activity. The implementation of player interchanges appeared to elicit a positive effect on the cumulative fatigue response observed for the perceptual and physiological measures, with a trend for increased rate of post-trial recovery of both moderate and fast speed eccentric KF PT. The use of player interchanges may therefore be beneficial to reduce injury risk during periods of congested match-play (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Orchard et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015).

A novel active recovery protocol was also designed in an attempt to artificially aid the rate of mechanical and perceptual recovery following the completion of soccer-specific activity. It was identified that the recovery protocol elicited a beneficial effect on the maximal

elongation capacity of the KF musculature, thus potentially being beneficial in reducing injury risk, particularly during periods of fixture congestion (Dupont et al., 2010; Ekstrand et al., 2011; Carling et al., 2012; Bengsston et al., 2013; Nédélec et al., 2013; Dellal et al., 2015. Although the active recovery protocol did not elicit any beneficial effects on any of the other mechanical or perceptual measures, it was identified that it also did not elicit any deleterious effects.

CHAPTER TEN

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